

# US and USSR Spacecraft Positions on the Moon: Understanding the Geologic Context and other things

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2010 Lunar Science Forum

# Motivation

Apollo sample and measurement locations are well controlled (even better with LROC).

Location uncertainties of robotic space up to km.

Surface spacecraft can provide geodetic control.

Place all locations in a uniform coordinate system.

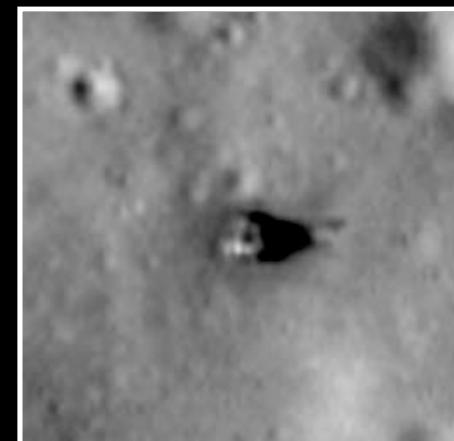
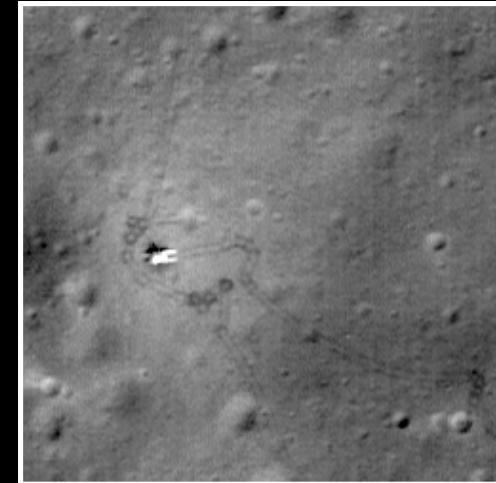
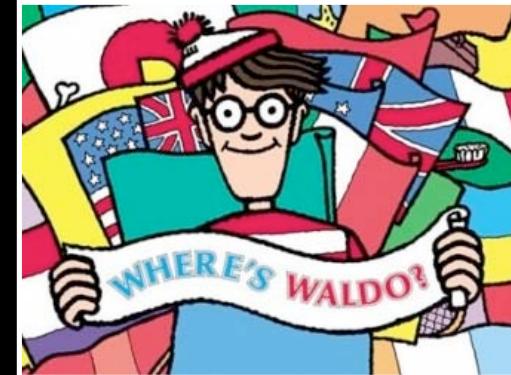
Geologic context of returned samples (Luna) and chemical analyses (Surveyor, Lunokhod)

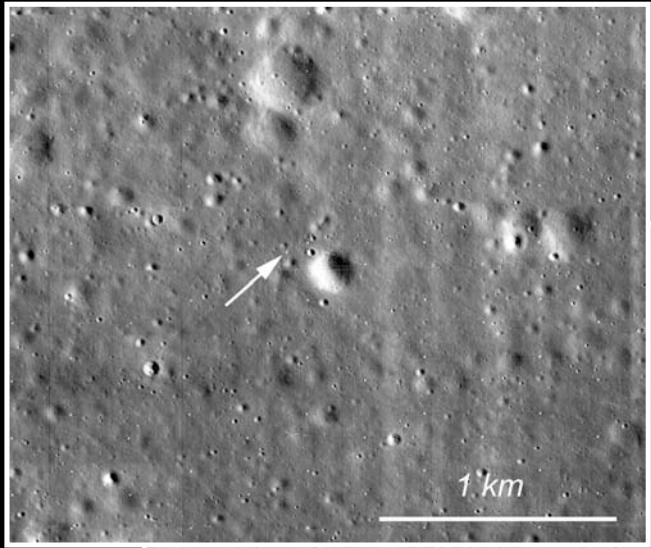
Spatial distribution of physical properties measurements (Lunokhod – wheel tracks and cone penetrometer)

Accurate traverse maps (Apollo, Lunokhod)

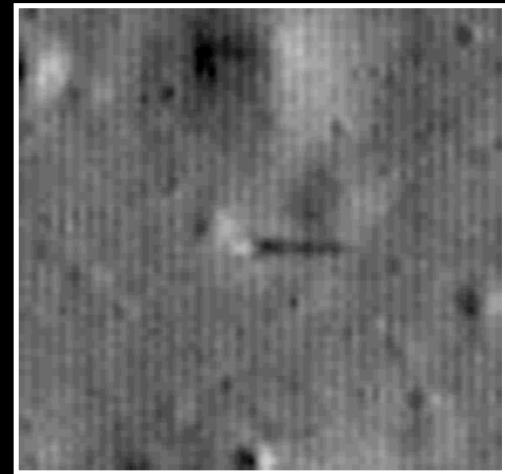
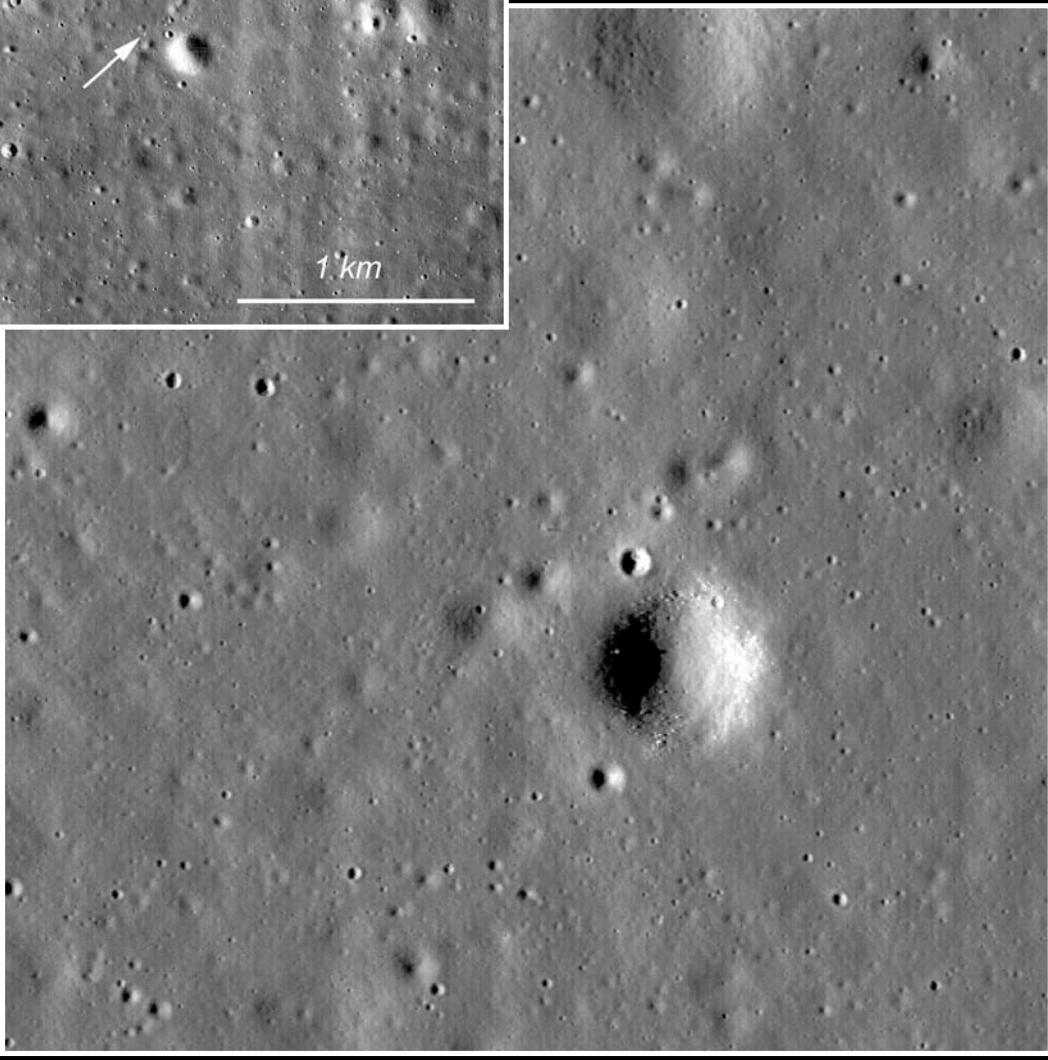
Range of descent engine plumes / surface interactions

Provide better position control for sources (e.g., SIVB impact) and receivers (ALSEP).

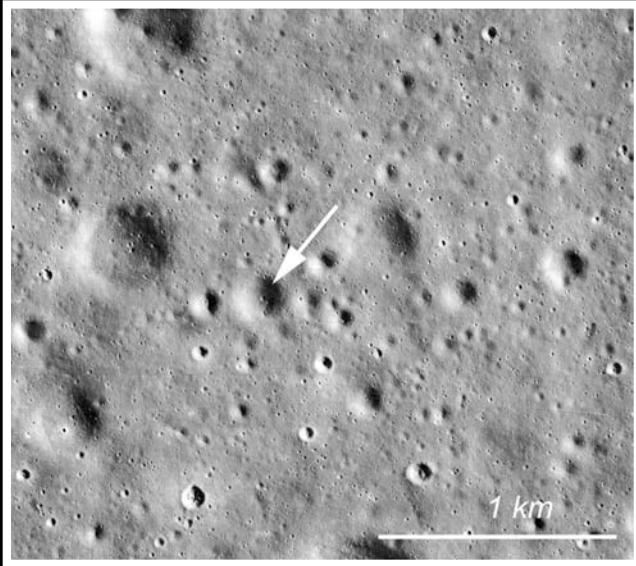




Surveyor 1



Oceanus Procellarum  
Landed: June 2, 1966  
EOM: January 7, 1967  
1<sup>st</sup> US Soft Landing  
11,237 images  
292 kg on landing



## Surveyor 3

Oceanus Procellarum

Southeast inner wall of Surveyor Crater

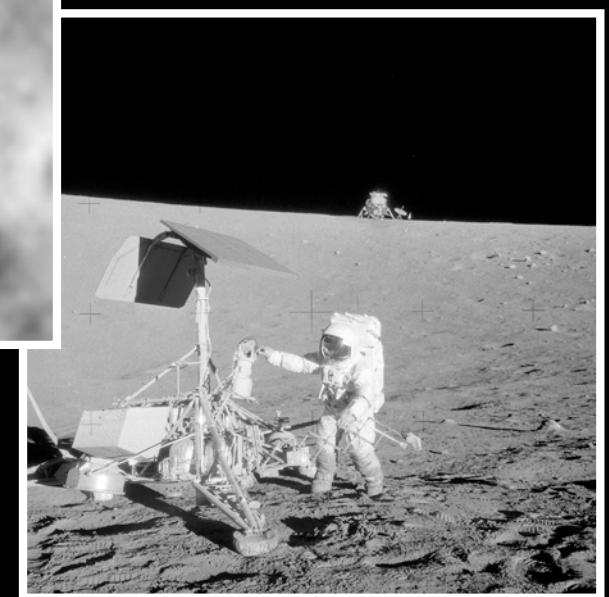
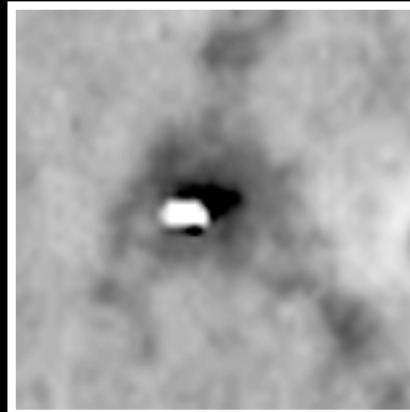
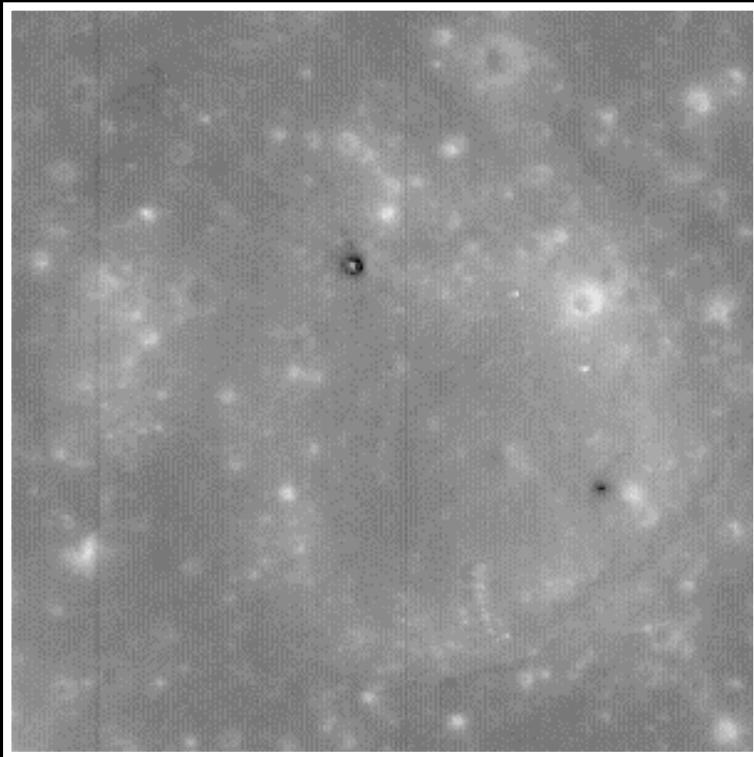
Landed: April 20, 1967

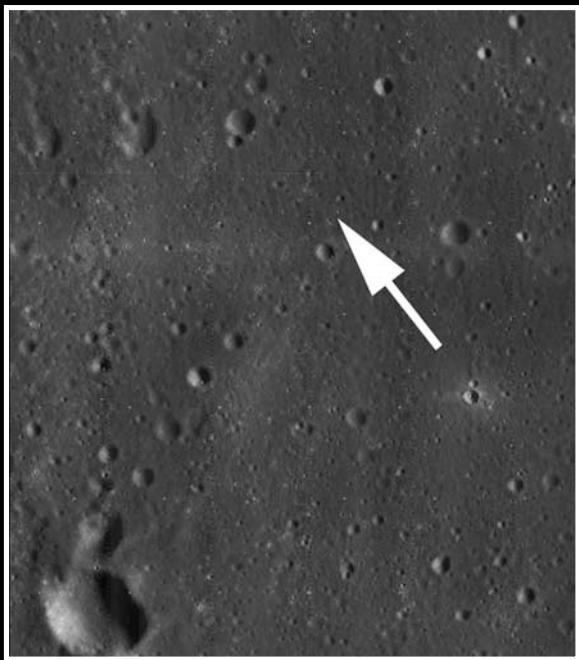
EOM: Did not survive the lunar night

Visited by Apollo 12, some hardware returned

6,315 images

302 kg on landing





## Surveyor 5

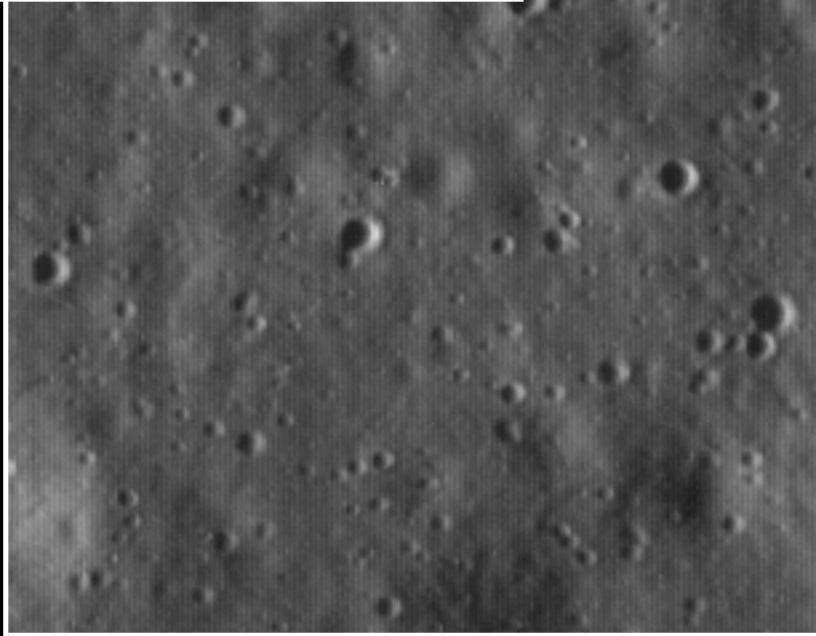
Mare Tranquillitatis

Landed: September 11, 1967

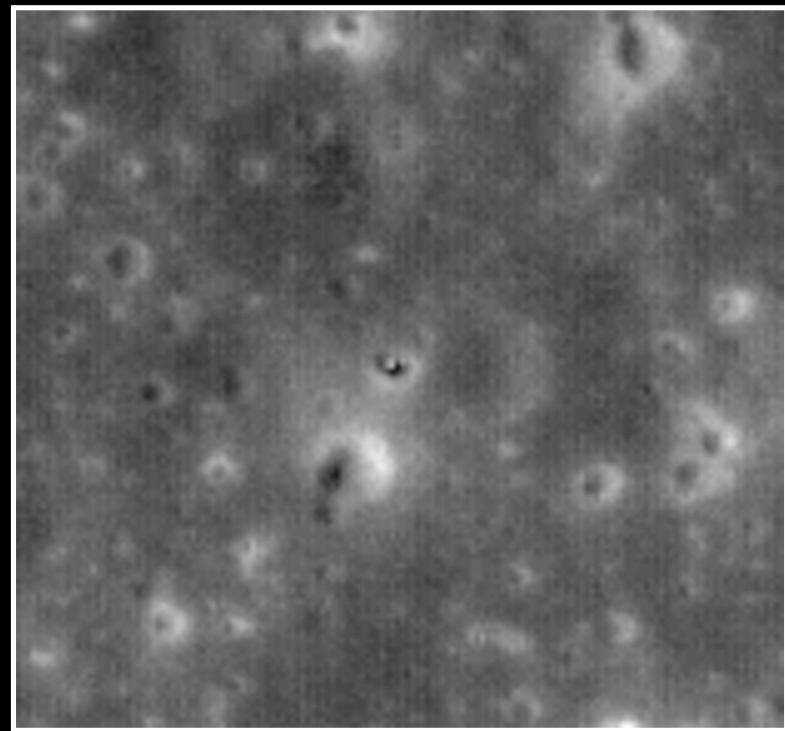
EOM: December 17, 1967

19,049 images

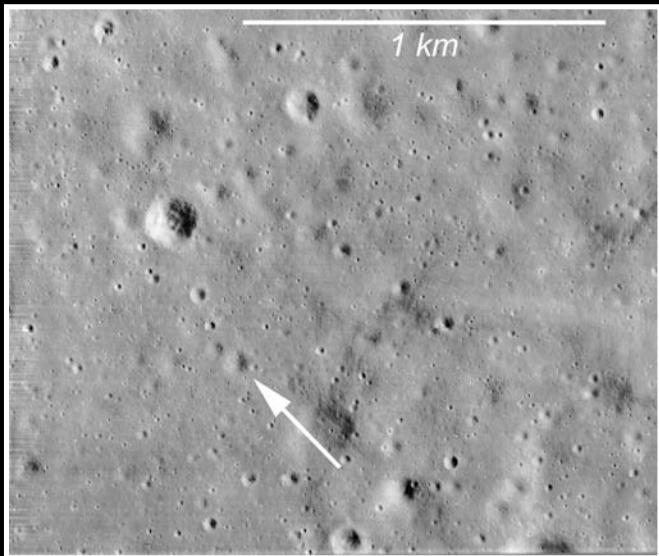
303 kg on landing



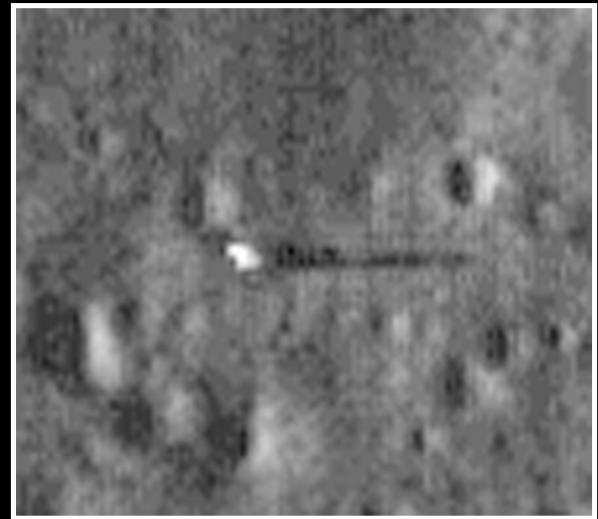
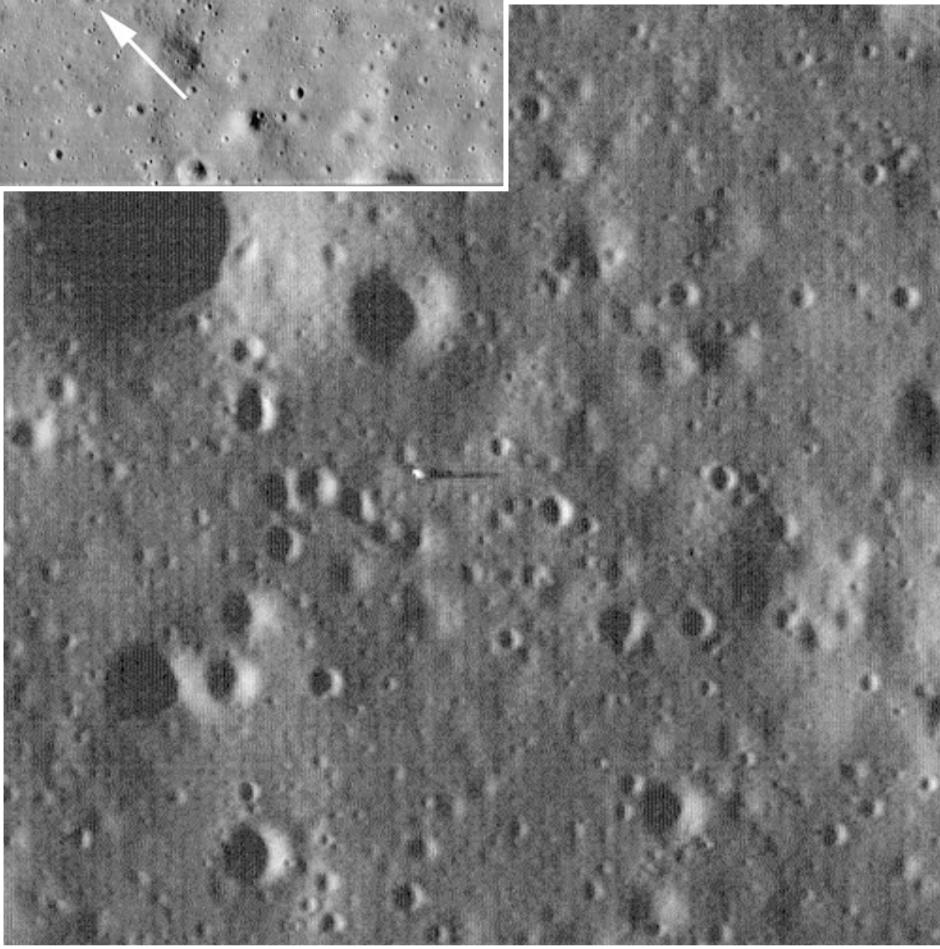
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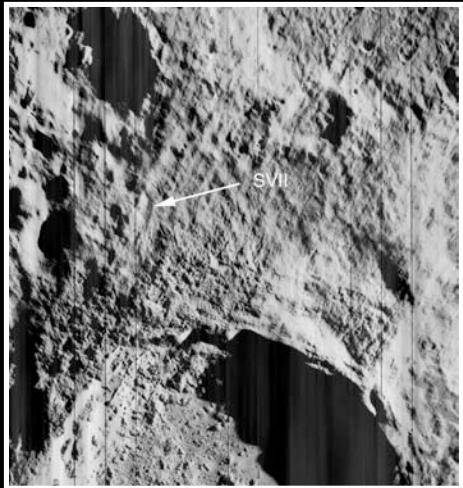
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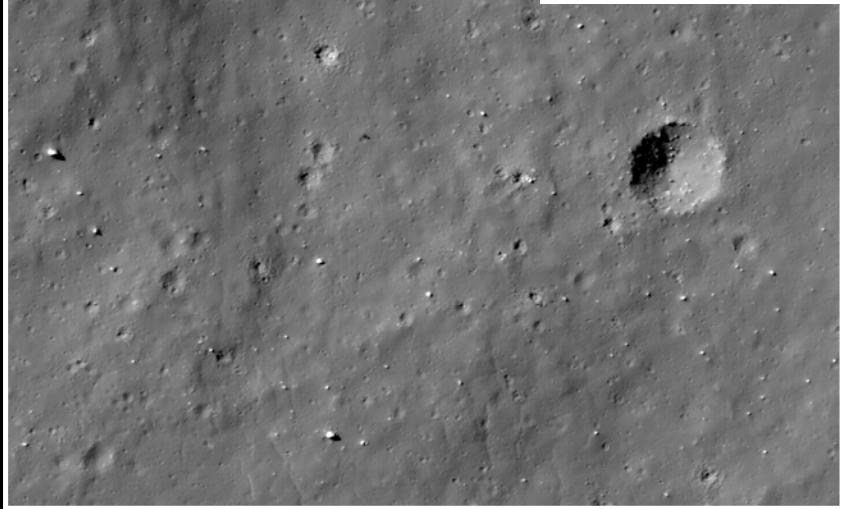
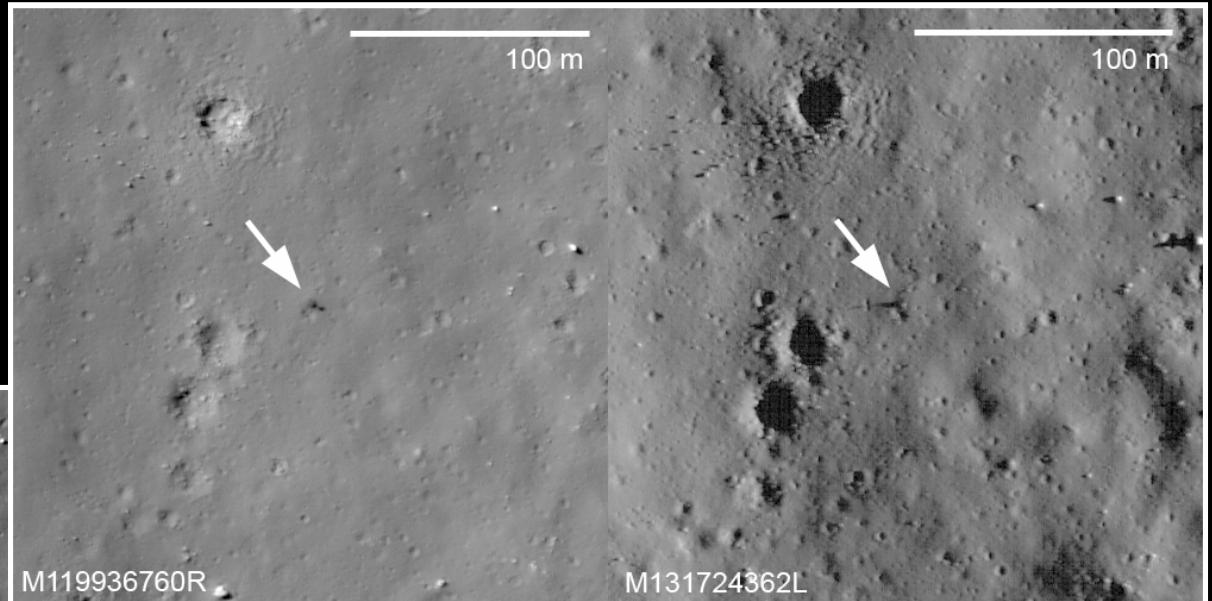
## Surveyor 6



Sinus Medii  
Landed: November 10, 1967  
EOM: December 14, 1967  
30,027 images  
299.6 kg on landing

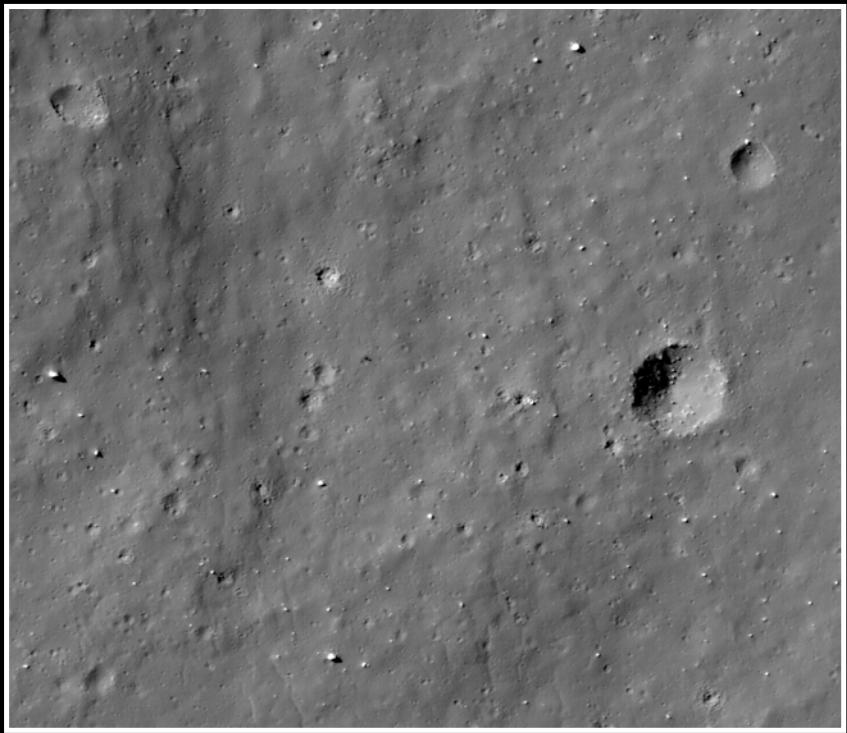
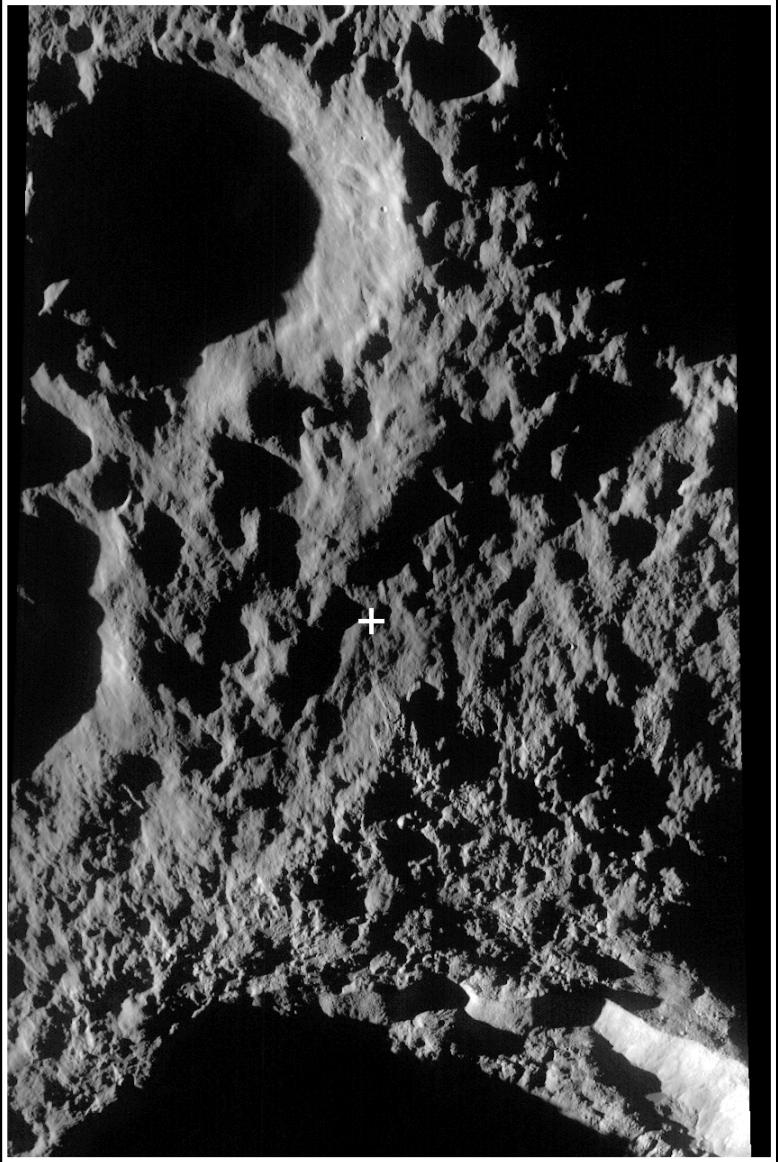


# Surveyor 7

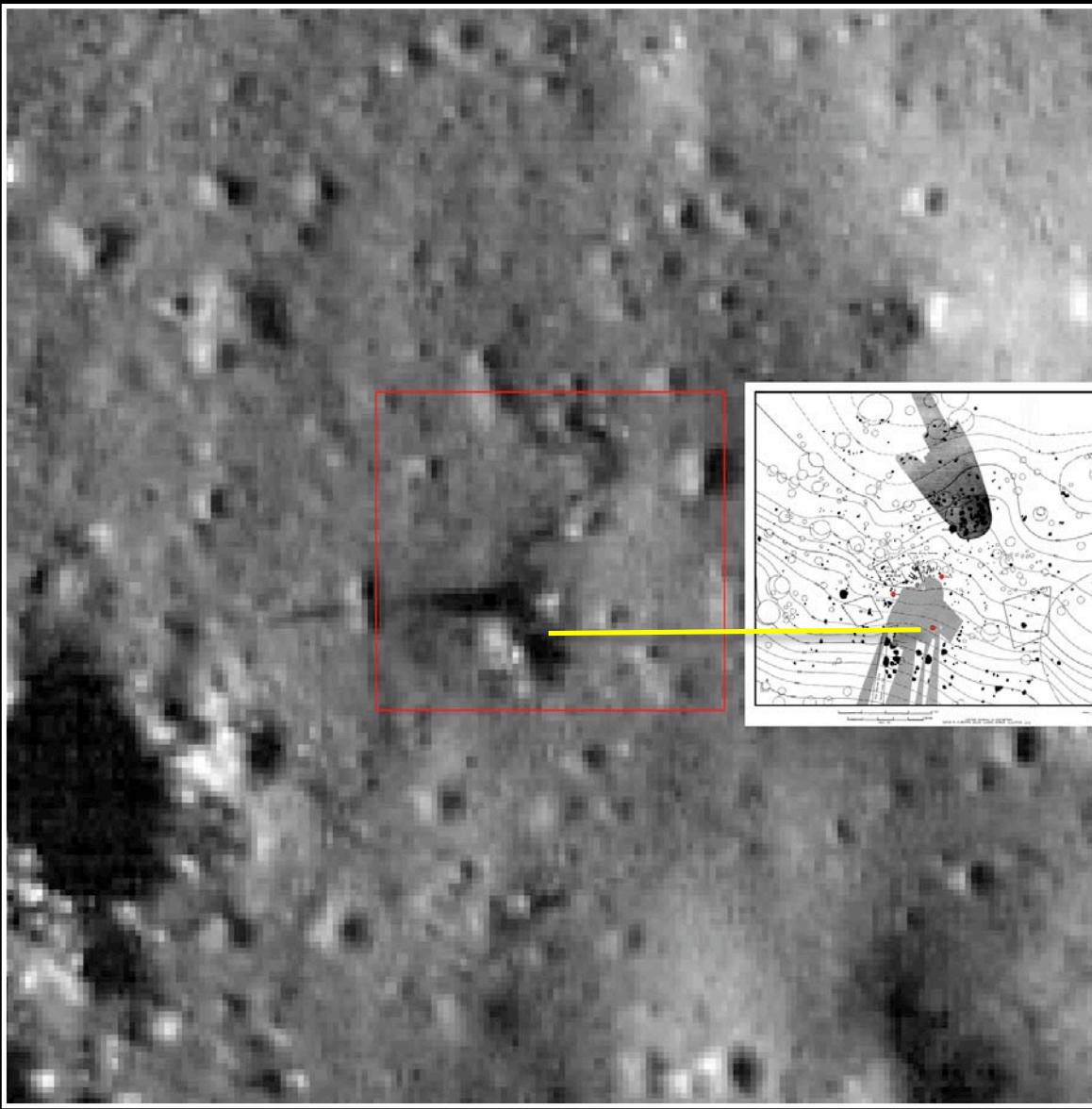


Northern margin of Tycho  
Landed: January 10, 1968  
EOM: February 20, 1968  
21,091 images  
305.7 kg on landing

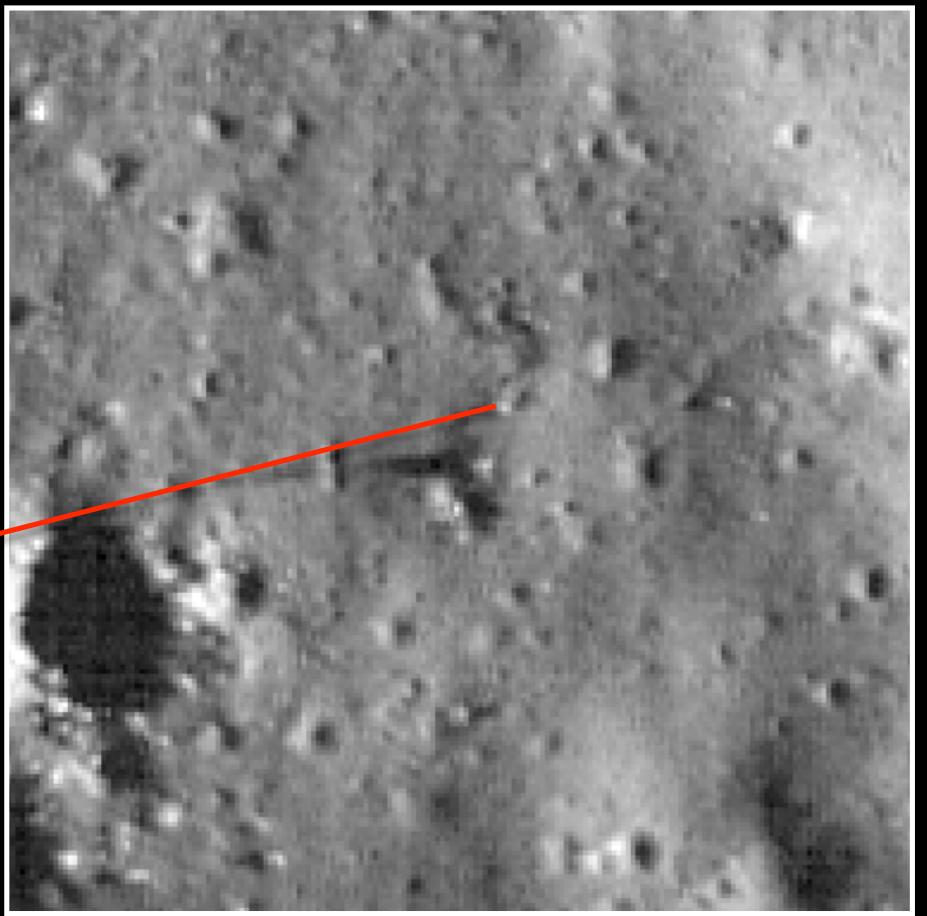
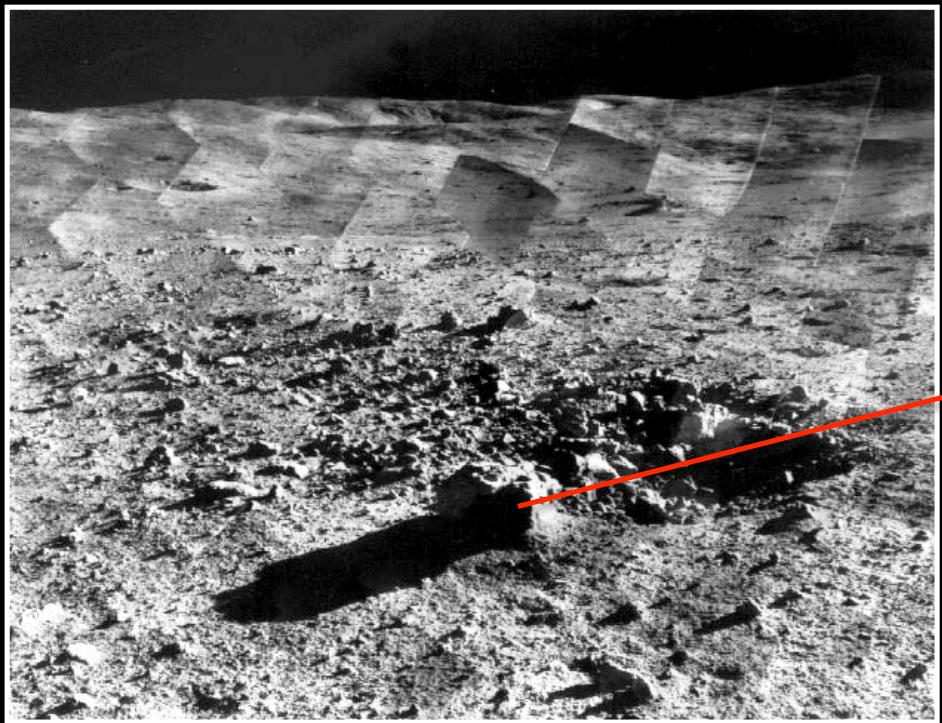
# Surveyor 7



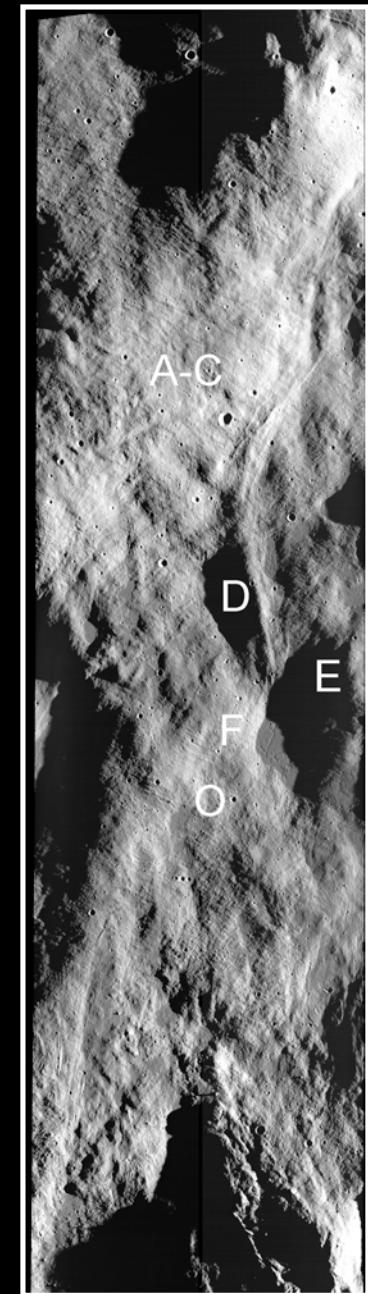
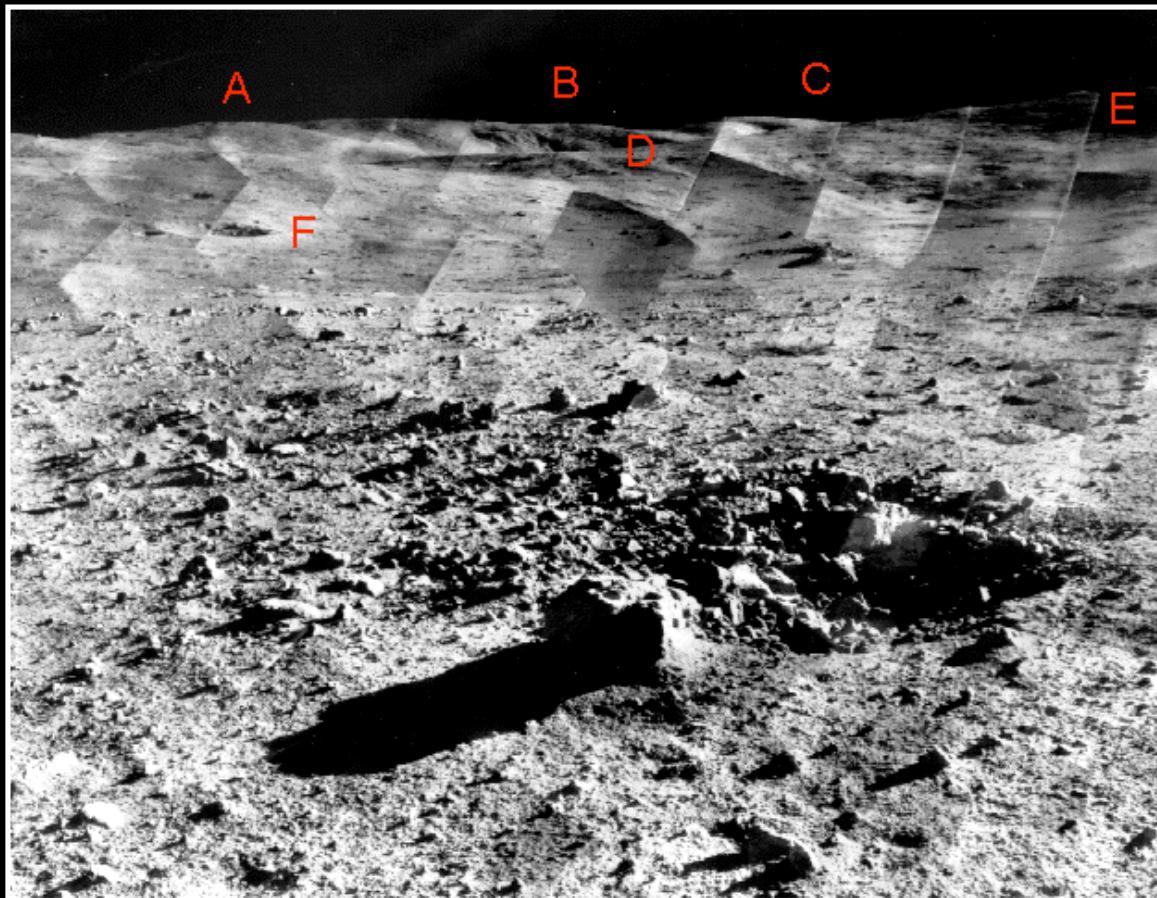
# Surveyor 7



# Surveyor 7



# Surveyor 7



View to the north and northeast

# Ranger 9

Alphonsus

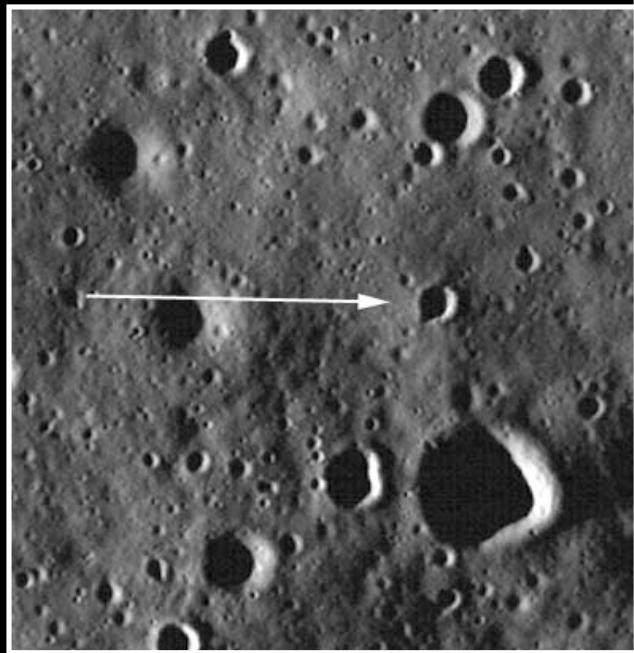
Impact: March 24, 1965

2.671 km / sec

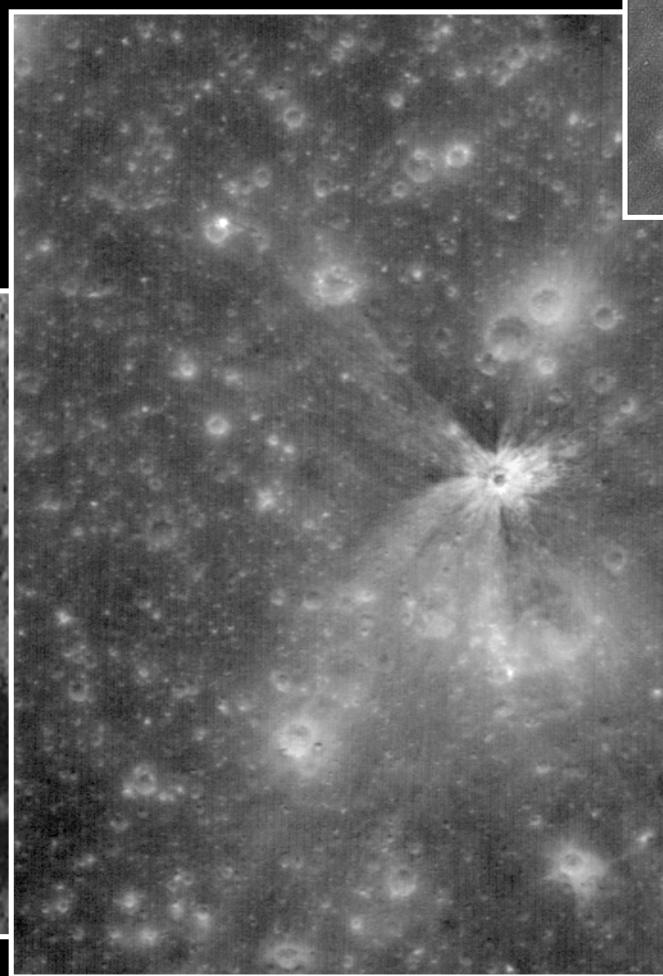
369.7 kg

64.9° from horizontal

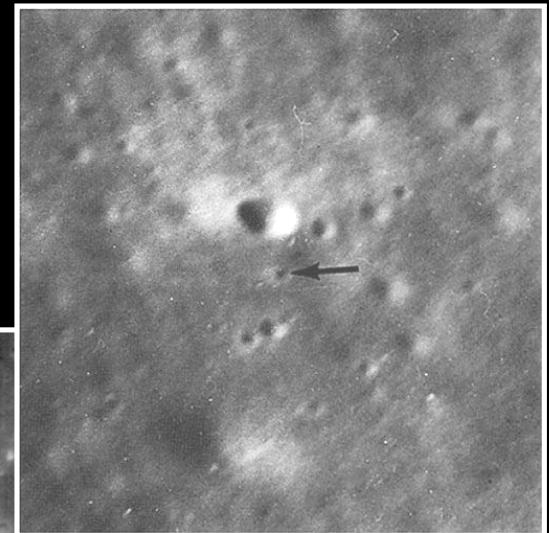
16 m crater



M117507817L



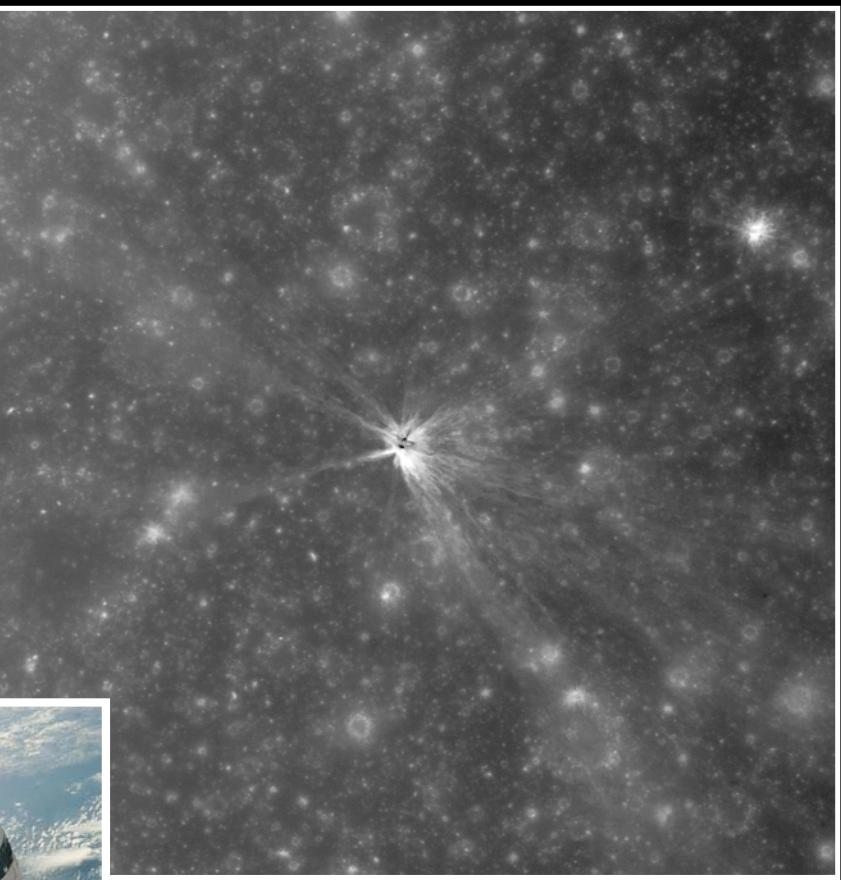
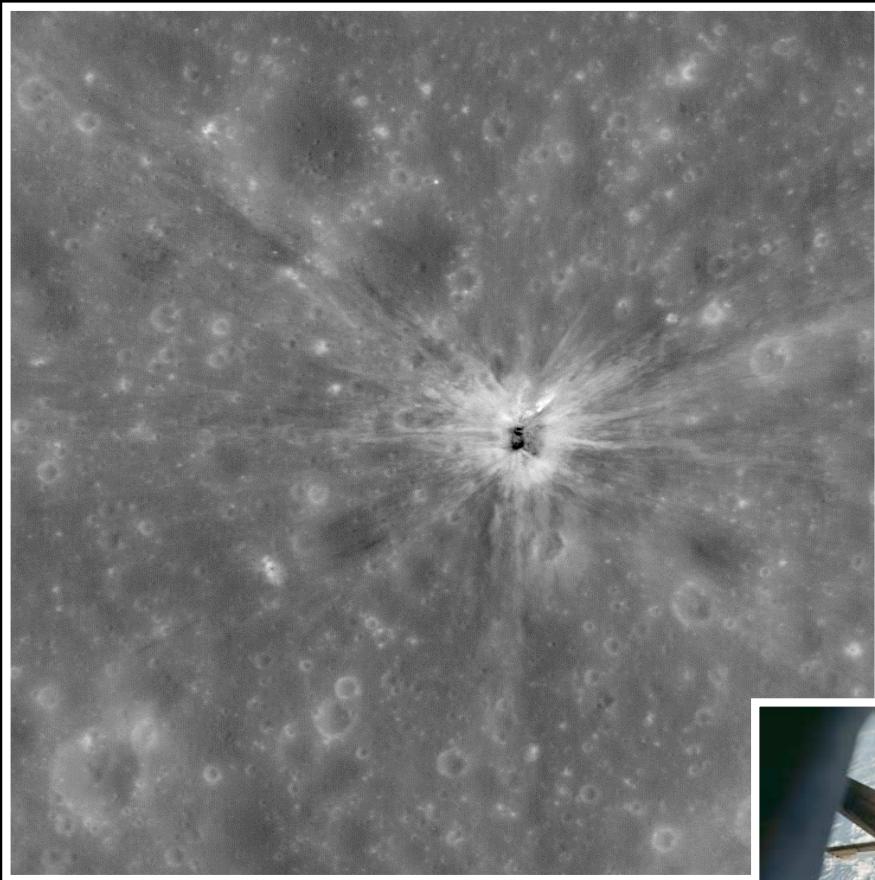
M109250398R



# Apollo SIVB

A13 SIVB: April 14, 1970  
2.58 km / sec  
13925 kg  
76° from horizontal  
41 m crater

A15 SIVB: July 29, 1971  
2.58 km / sec  
8465 kg  
62° from horizontal

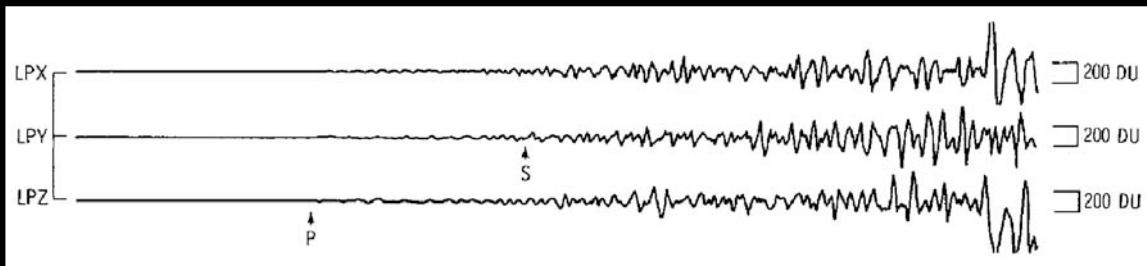


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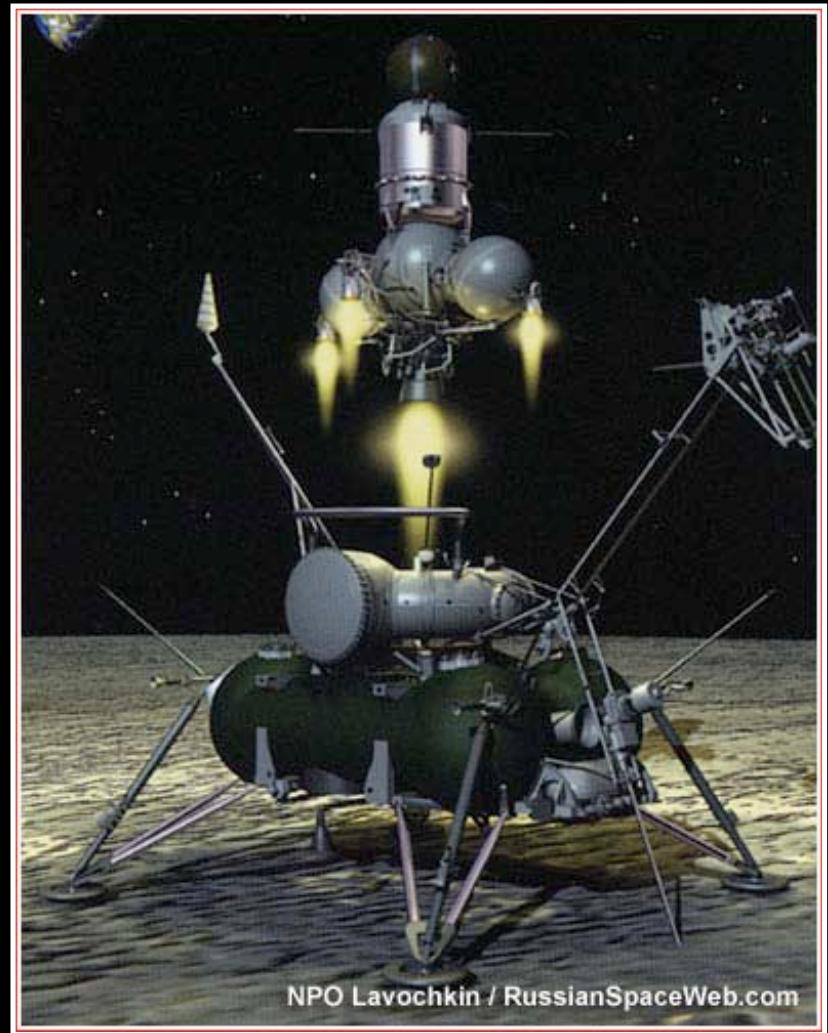
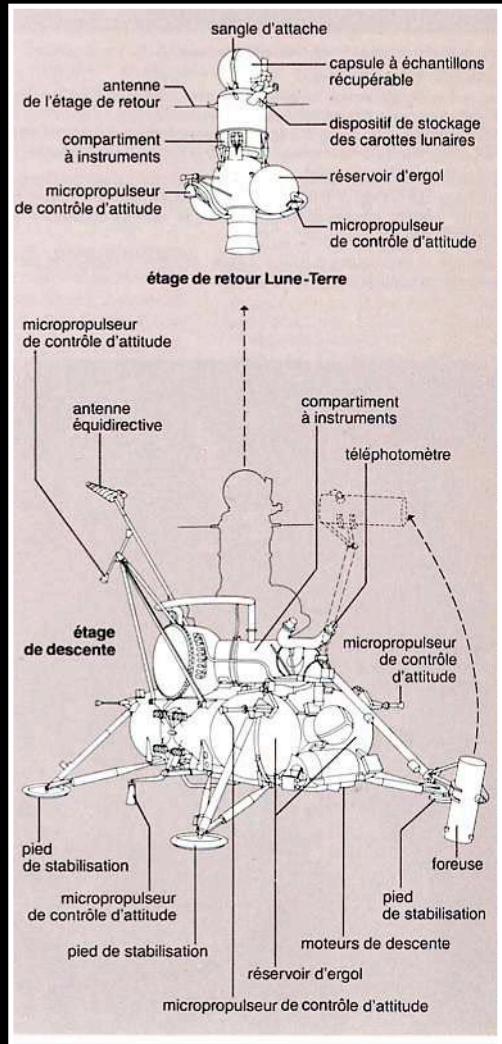
# Coordinates – Apollo Era Uncertainties

Target	N		Lat	Long
<b>Ranger 6</b>	2	Average	9.386562	21.479328
		Std Dev	0.001795	0.001288
		Std Dev (m)	54.4	39.1
		Delta JPL-LROC	-0.056562	0.040672
		Delta (m)	-1715.7	1233.7
<b>Ranger 7</b>	1	Average	-10.632652	339.322939
		Std Dev		
		Std Dev (m)		
		Delta JPL-LROC	-0.067348	0.007061
		Delta (m)	-2042.9	214.2
<b>Ranger 8</b>	2	Average	2.637215	24.784645
		Std Dev	0.001443	0.003398
		Std Dev (m)	43.8	103.1
		Delta JPL-LROC	0.072785	0.025355
		Delta (m)	2207.8	769.1
<b>Ranger 9</b>	4	Average	-12.828047	357.611318
		Std Dev	0.000743	0.006764
		Std Dev (m)	22.5	205.2
		Delta JPL-LROC	-0.081953	0.008682
		Delta (m)	-2485.9	263.3

Target	N		Lat	Long
<b>A13 SIVB</b>	2	Average	-2.553896	332.112773
		Std Dev	0.001042	0.000586
		Std Dev (m)	31.6	17.8
		Delta JPL-LROC	-0.196104	0.027227
		Delta (m)	-5948.6	825.9
<b>A14 SIVB</b>	4	Average	-8.179411	333.969219
		Std Dev	0.001200	0.000963
		Std Dev (m)	36.4	29.2
		Delta JPL-LROC	0.089411	0.010781
		Delta (m)	2712.2	327.0
<b>A15 SIVB</b>	2	Average	-1.287925	348.175731
		Std Dev	0.000517	0.000292
		Std Dev (m)	15.7	8.9
		Delta JPL-LROC	-0.222075	0.014269
		Delta (m)	-6736.4	432.8
<b>A17 SIVB</b>	3	Average	-4.16731	347.67039
		Std Dev	0.00046	0.00023
		Std Dev (m)	14.0	6.9
		Delta JPL-LROC	-0.042685	0.019612
		Delta (m)	-1294.8	594.9

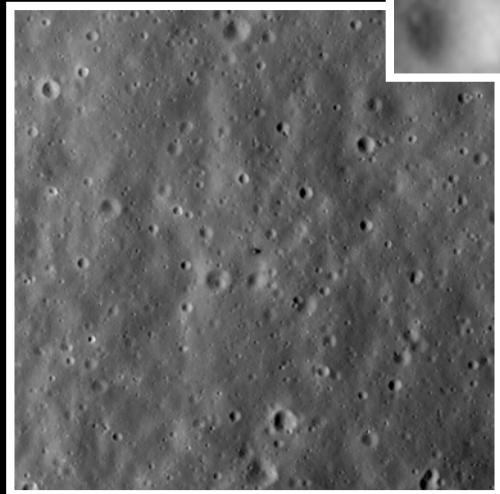
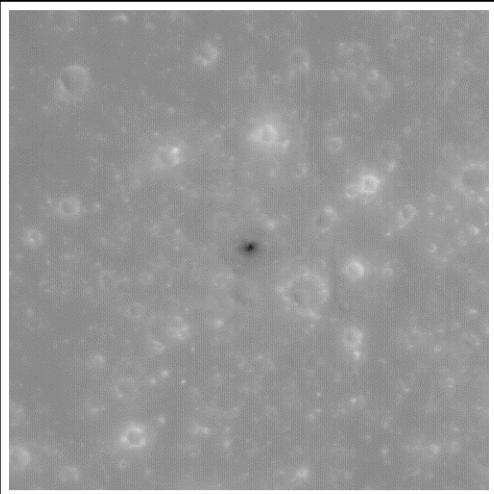
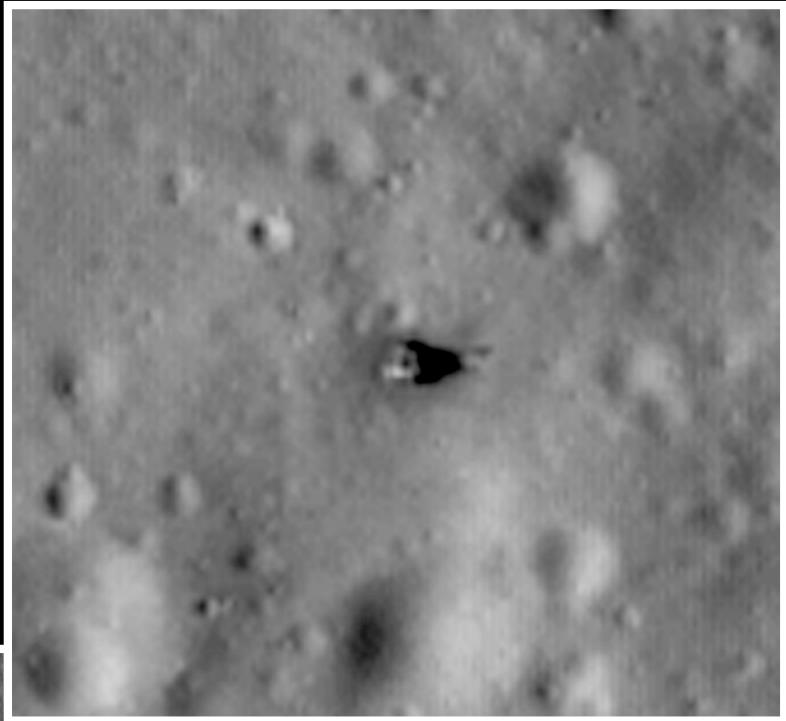
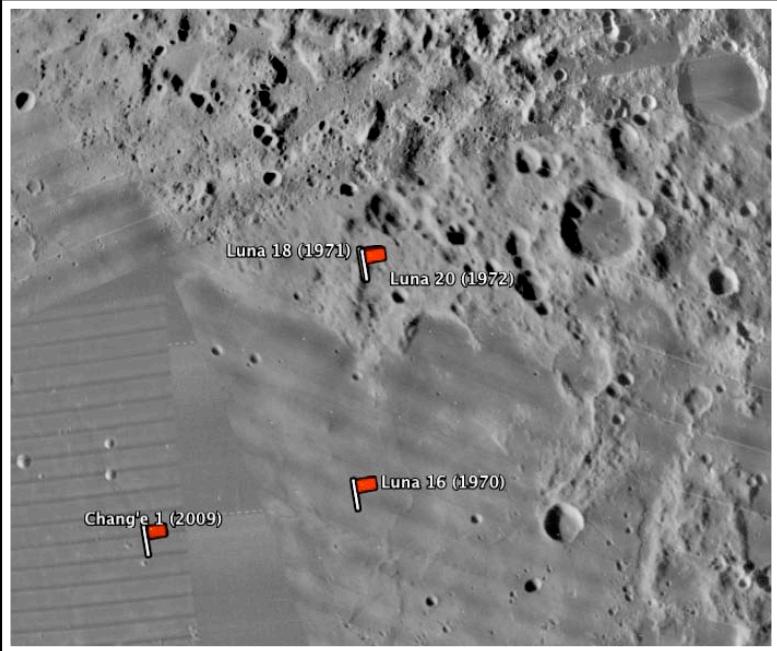


# Luna SR

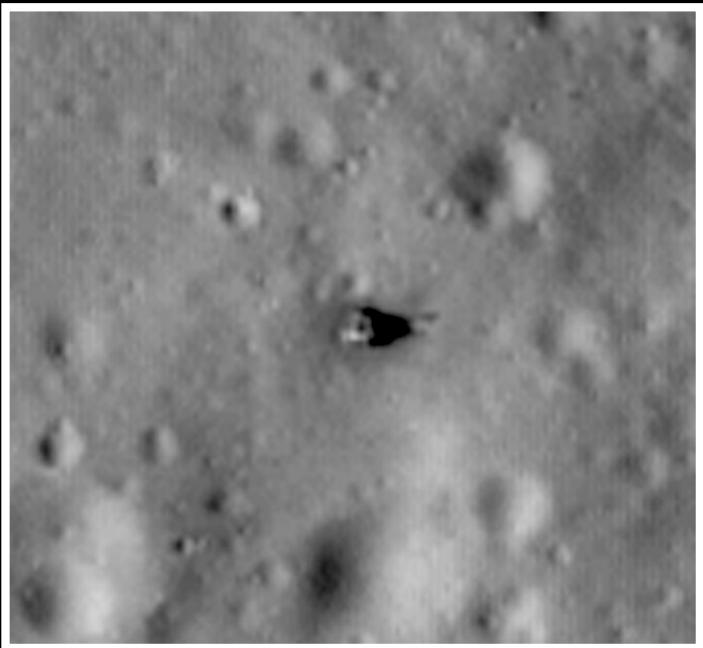


NPO Lavochkin / RussianSpaceWeb.com

# Luna 20



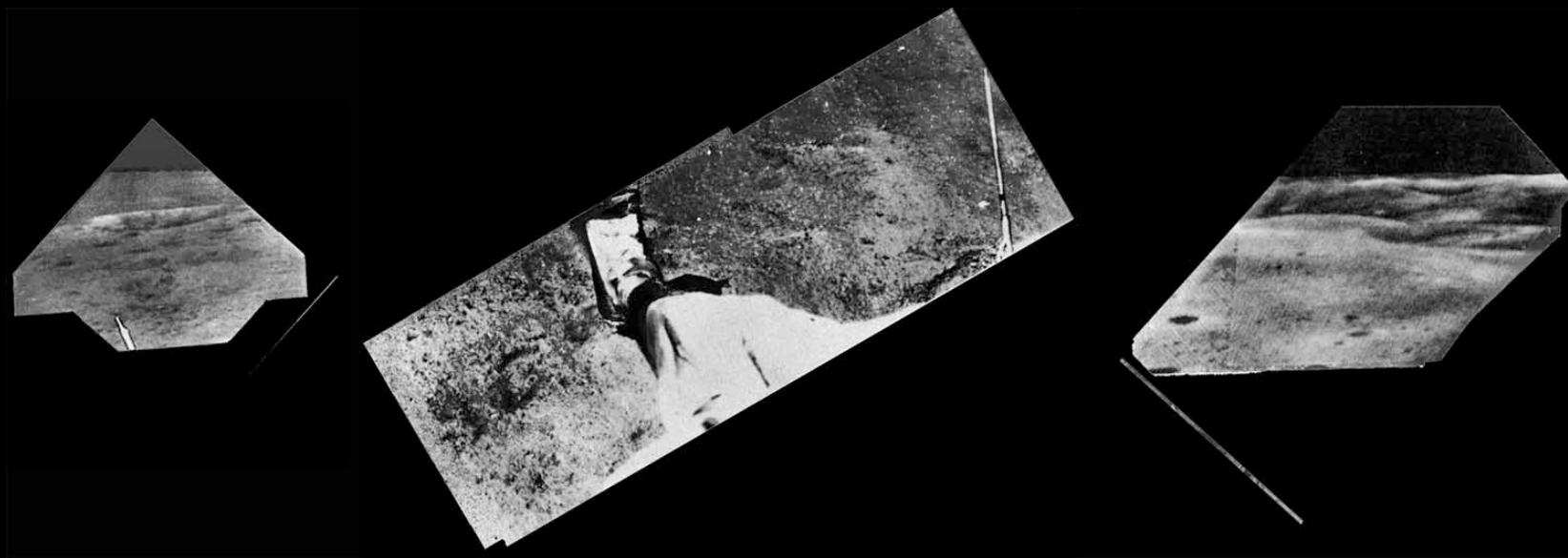
Highlands near Apollonius  
Landing: February 21, 1972  
Launch: February 22, 1972  
55 g sample return  
Mass: 5727 kg



## Luna 20

View from Luna 20 of the sampling arm (center) and the surrounding area.

Rolling cratered highlands.  
Luna 20 is on the southeast slope  
of a NE trending ridge.



# Luna 23 / 24

## Luna 23

Site: Mare Crisium – mare material

Landed: November 6, 1974

Landed intact, but did not acquire a sample due to technical failure

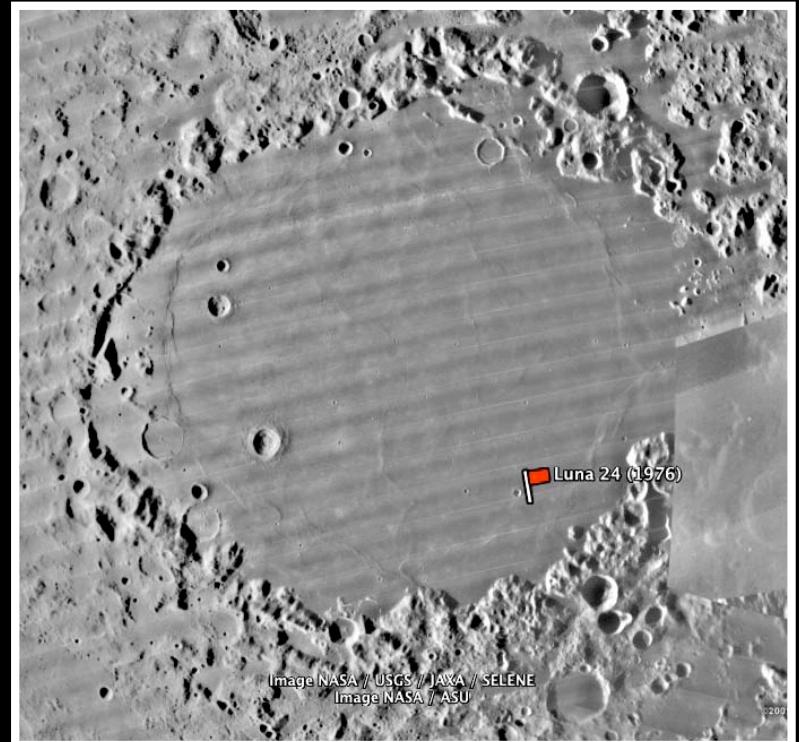
## Luna 24 (repeat of 23)

Site: Mare Crisium – mare material

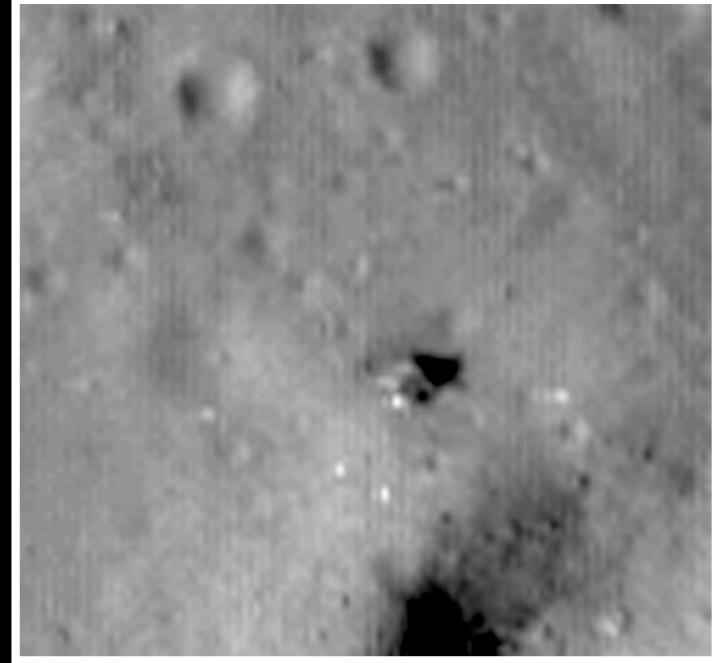
Landed: August 18, 1976

Liftoff: August 19, 1976

170.1 g sample



## Luna 24



S/C on the northwest flank of a 63 m crater  
Sample site is on continuous ejecta - ~1 m  
thick at sample site.  
Fresh crater: crisp morphology and bright  
rays to the NW - W – SE, absent to the NE.

# Luna 24

At time of mission:

Remote sensing data indicated 2-4 wt %  
 $\text{TiO}_2$ , samples contained ~1 wt %.  
(Subsequently Gillis et al. showed that that  
 $\text{TiO}_2$  content of the samples is consistent with  
the remote sensing data.)

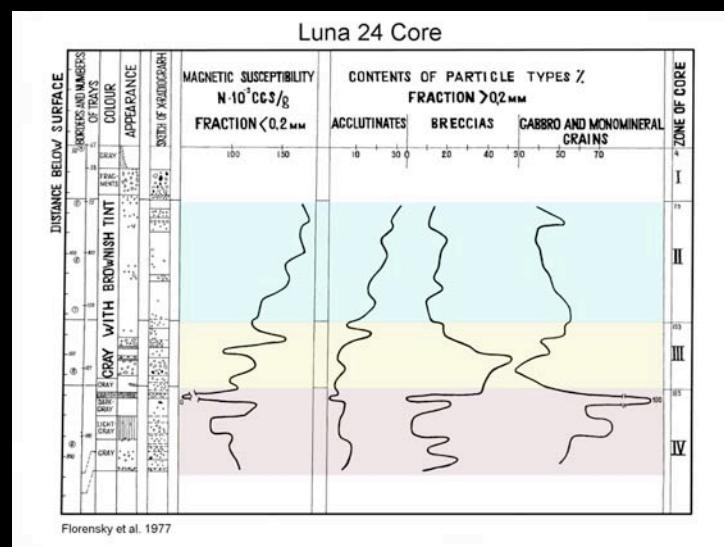
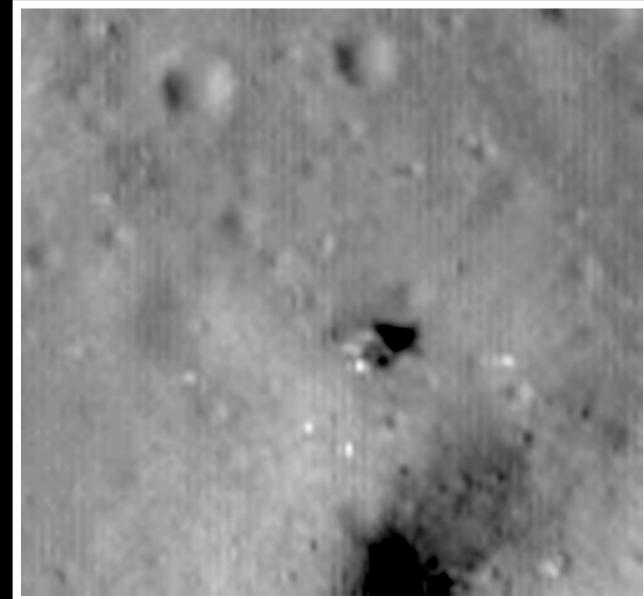
Samples:

Rock and mineral fragments.  
Mixture of materials (Bogard et al. 1978;  
McKay et al. 1978)  
Immature (Morris 1978)

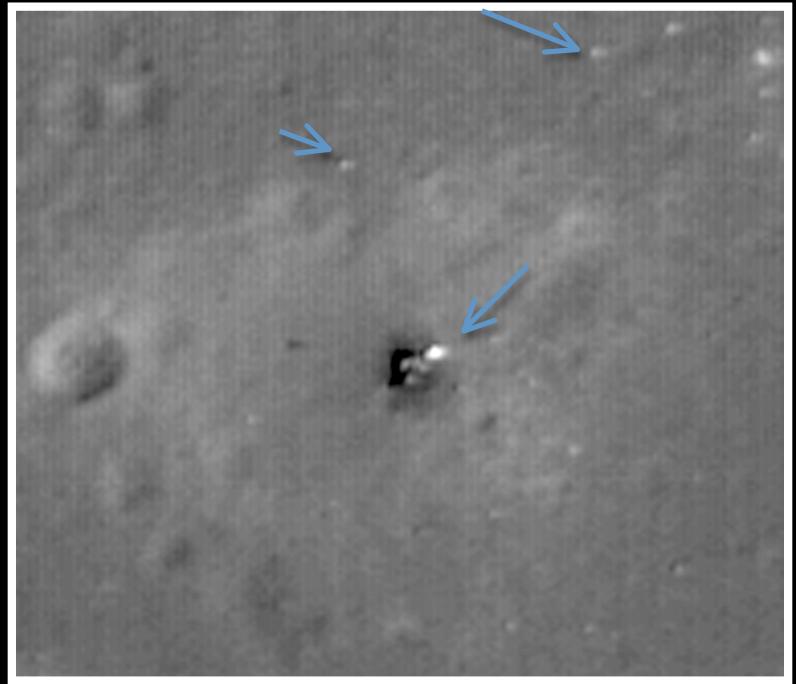
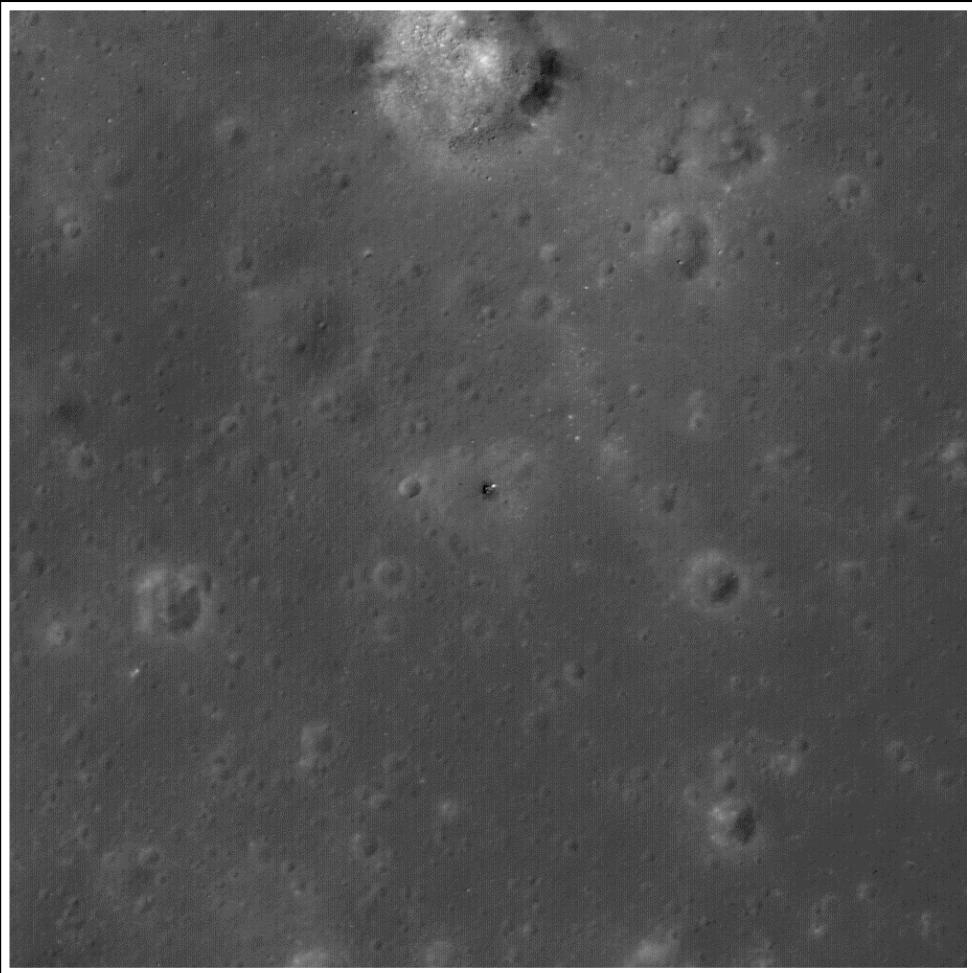
Conundrum: Why are samples different?

Ejecta ~1 m thick at sampling site.

Upper core is ejecta, lower part of the core  
may be Crisium mare material.

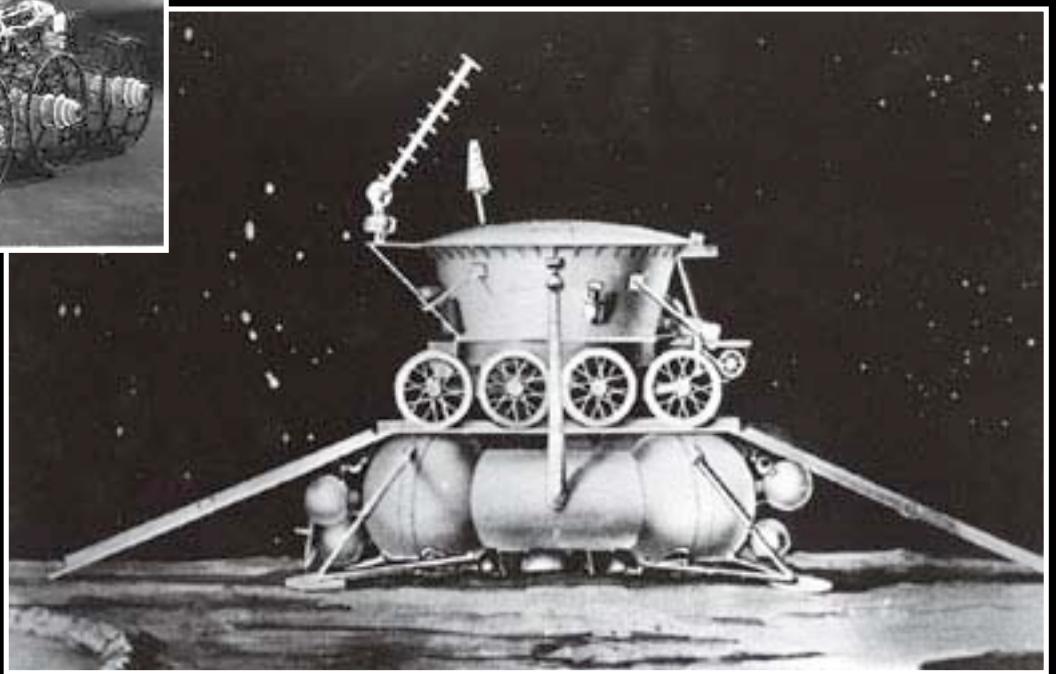
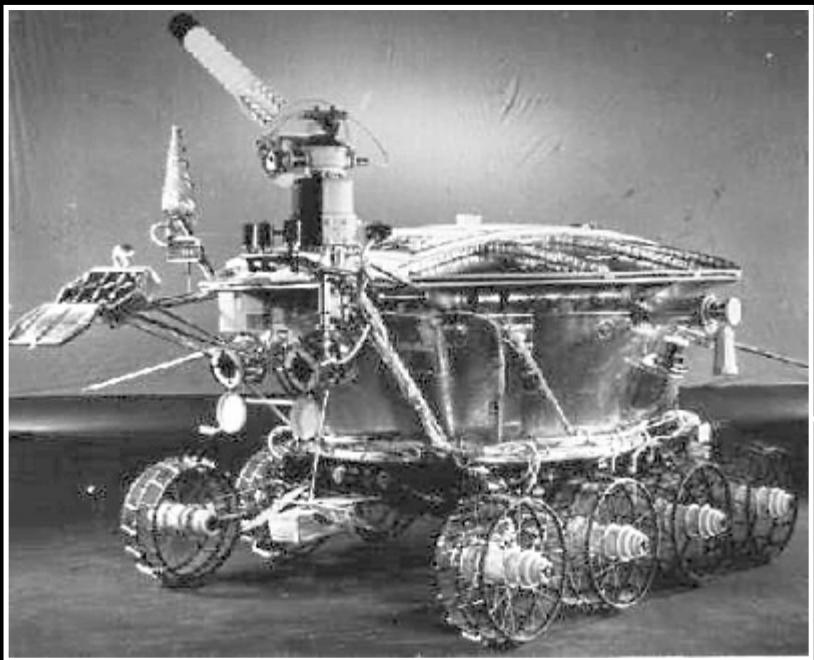


## Luna 23

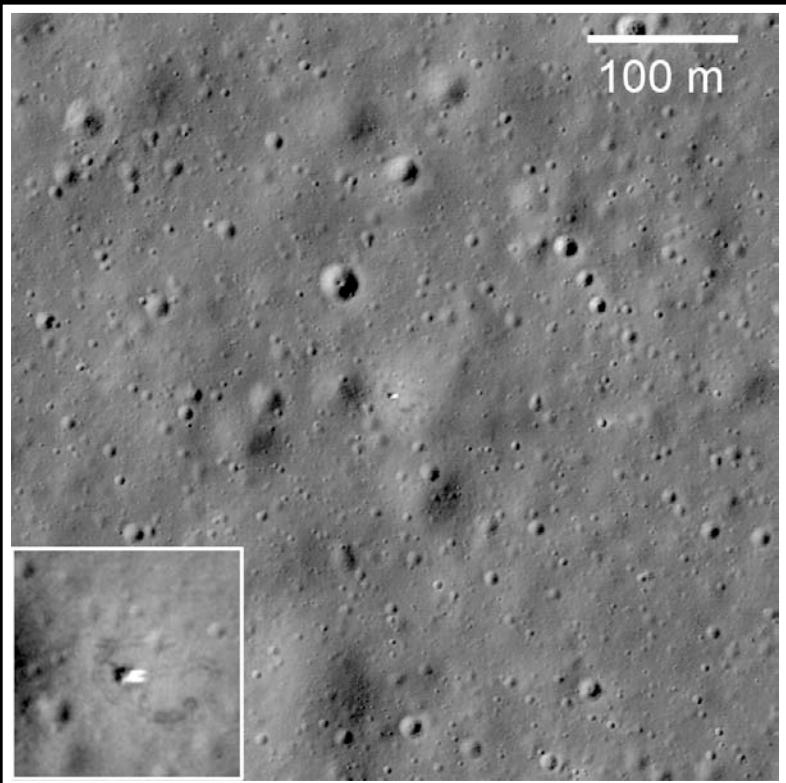


Spacecraft successfully landed but could not acquire sample. Cause of failure is unknown. Landing site is a typical mare surface. Scattered ejected boulders from crater to the north. Boulder may have caused failure.

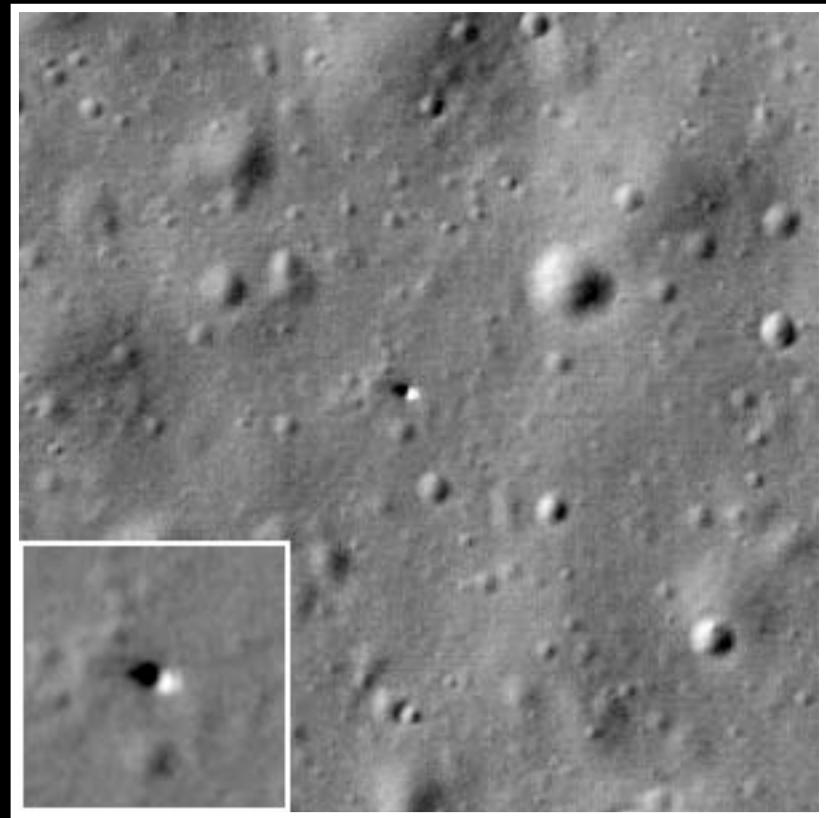
# Lunokhod 1-2



# Luna 17 / Lunokhod 1



Northwest Mare Imbrium  
Landed: November 17, 1970  
EOM: September 14, 1971  
Lander and Rover: 1814 kg



# Luna 17 / Lunokhod 1

Luna 17 / Lunokhod 1 launched: 11/10/70; landed 11/17/70, EOM: 9/14/71, Mission length: 322 days.

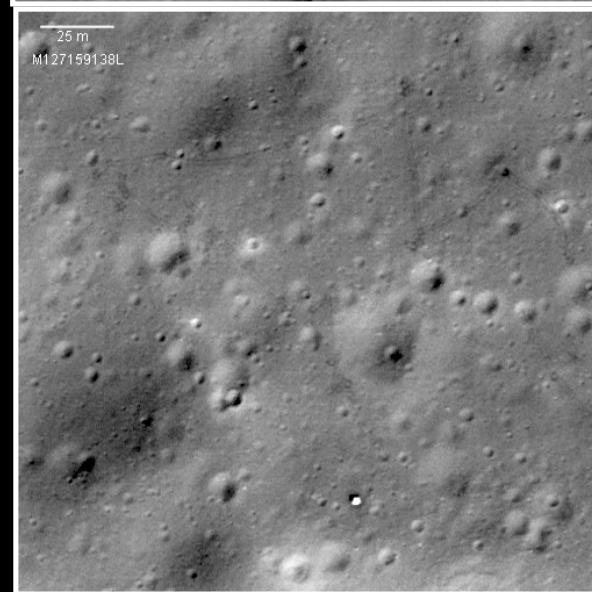
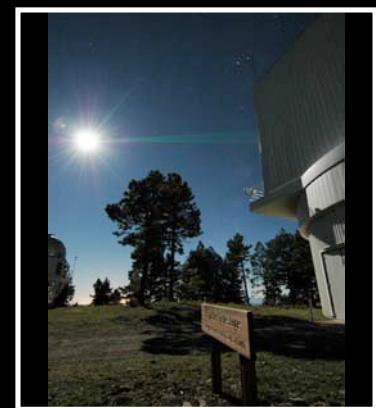
Lunokhod 1 covered 10.5 km across Mare Imbrium. Earth-based laser ranging for a few days during the mission, subsequently no signal.

LROC images used to locate the rover.

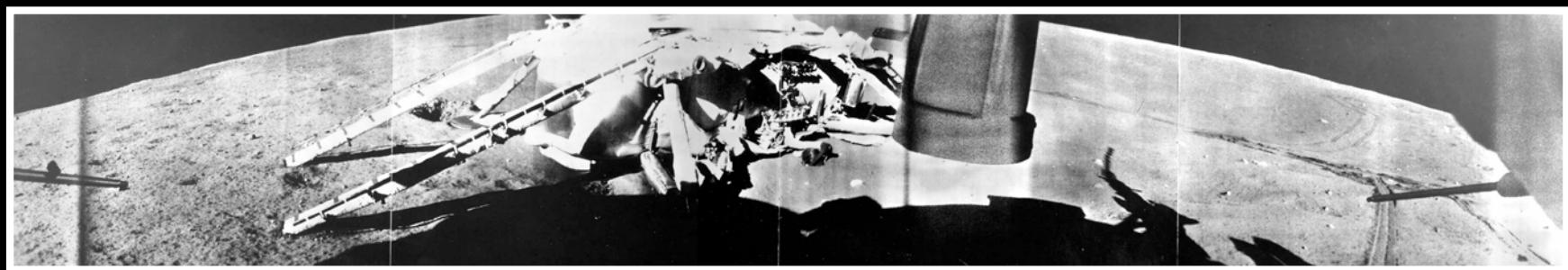
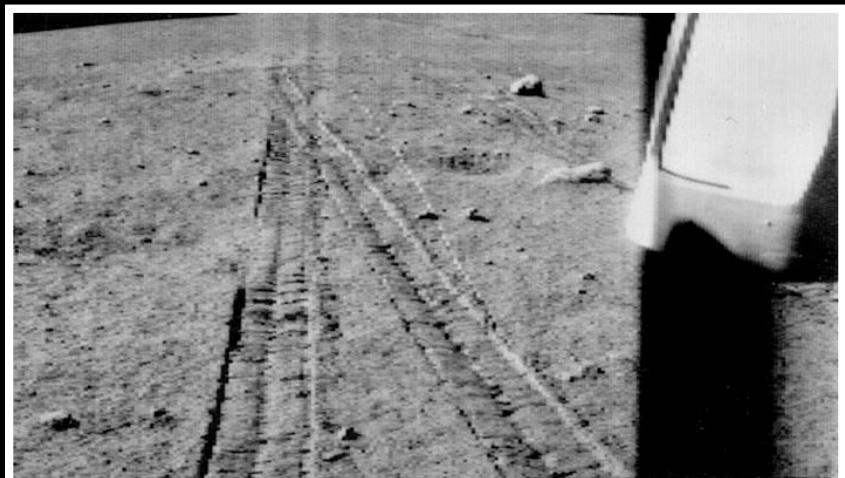
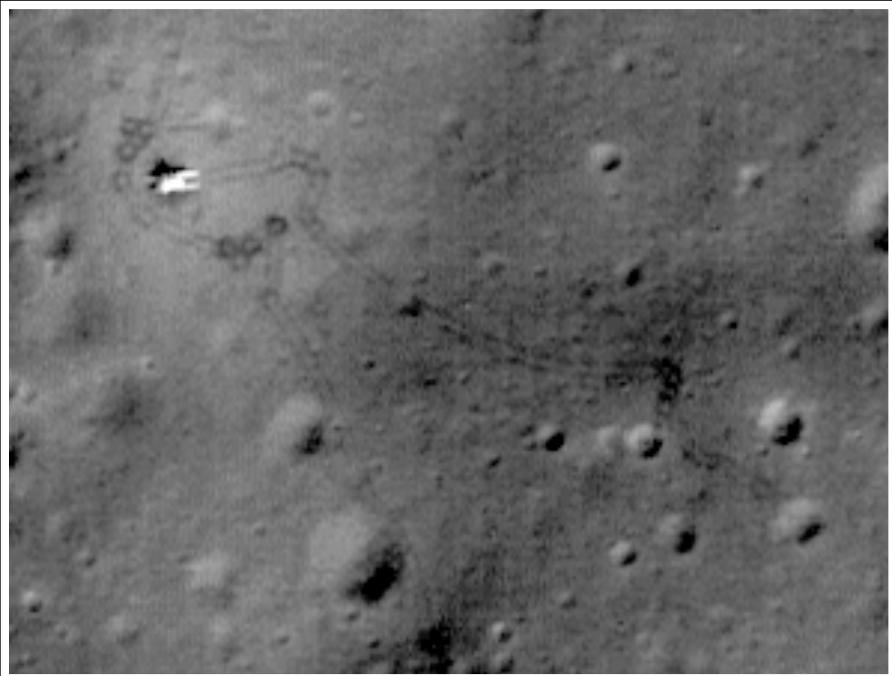
Coordinates sent to T. Murphy UCSD, subsequently he used Apache Point Lunar Laser to locate the rover.

Signal strength excellent.

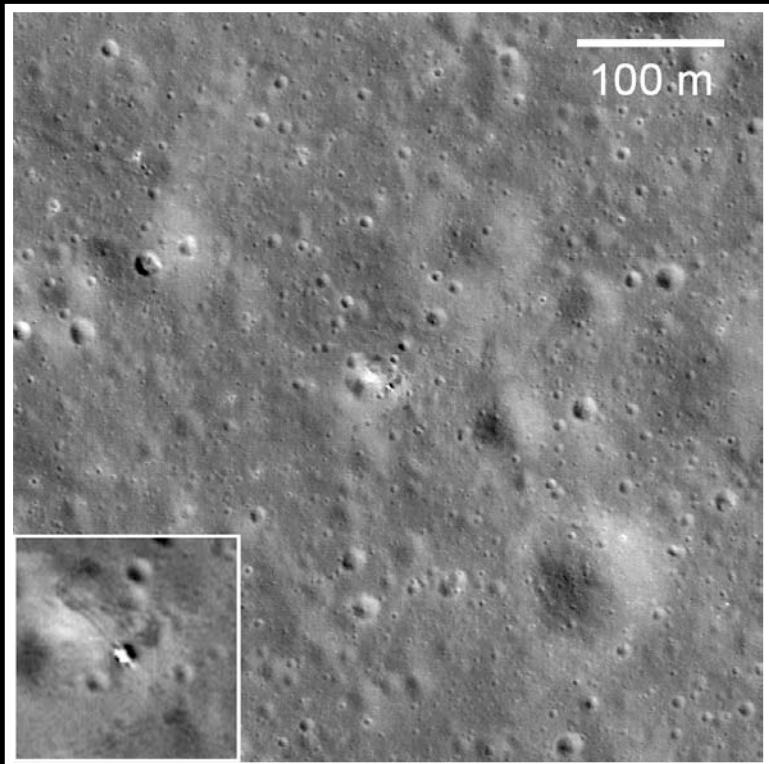
Significantly expands the spatial extent of the network of reflectors – better lunar geodesy and relativistic physics



# Luna 17 / Lunokhod 1



# Luna 20 / Lunokhod 2



Le Monnier Crater – mare surface

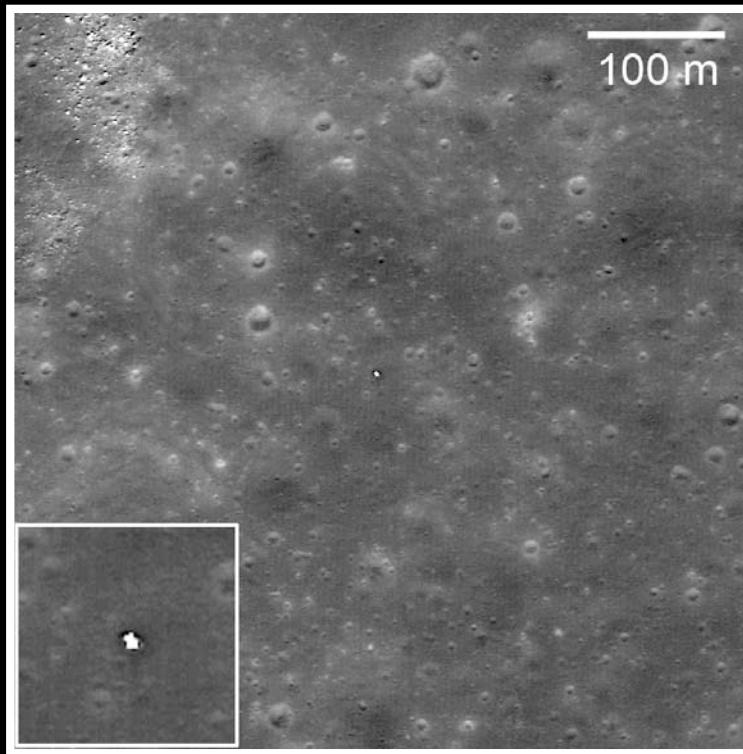
Landed: January 15, 1973

EOM: June 4, 1973

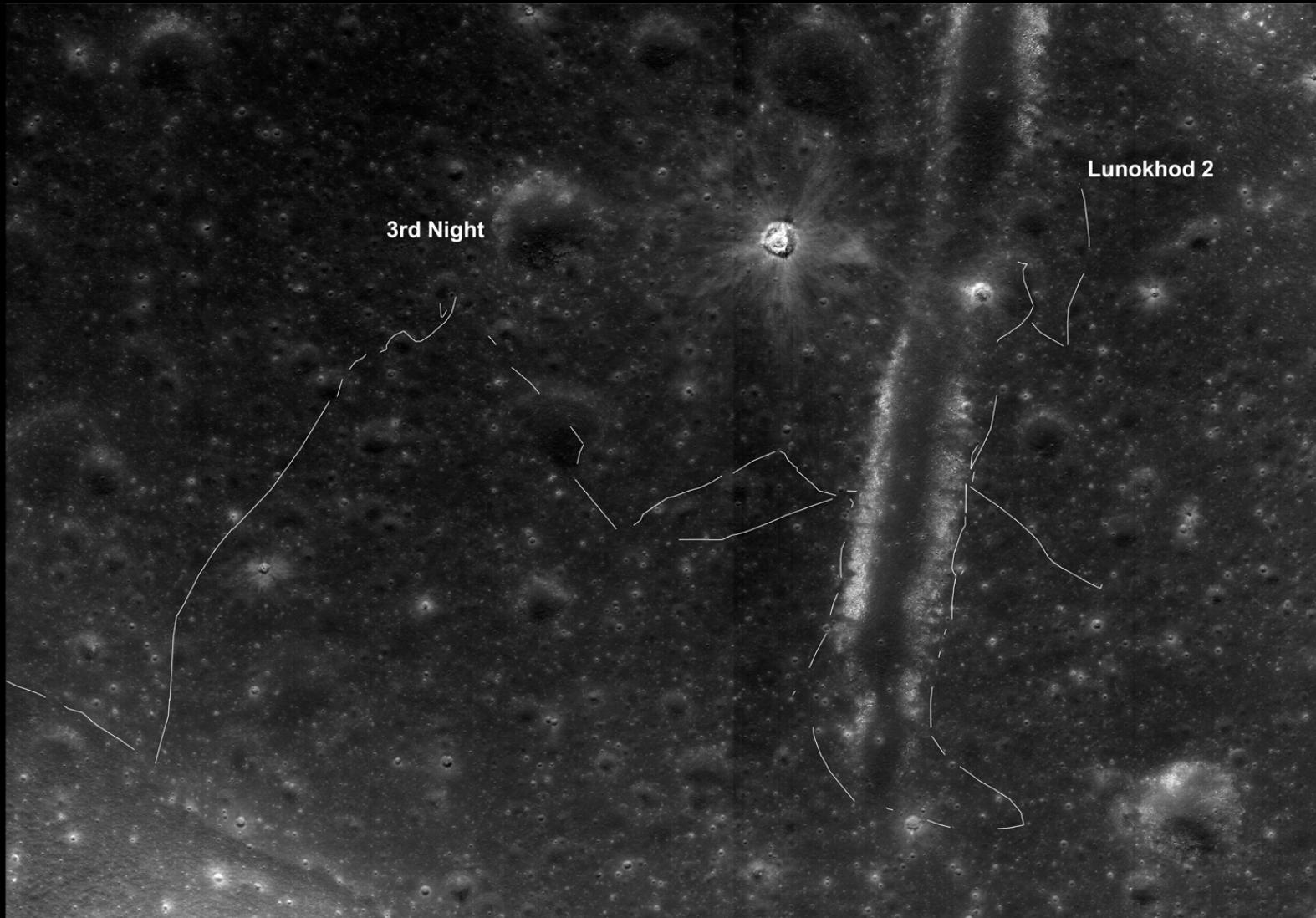
Lander and Rover: 1814 kg

Apparently overheated due to dust  
dumped on radiators

Sold to Richard Garriott for \$68,500



# Lunokhod 2



## Albedo Patterns

Albedo patterns associated with landed vehicles.

Best observed with high sun

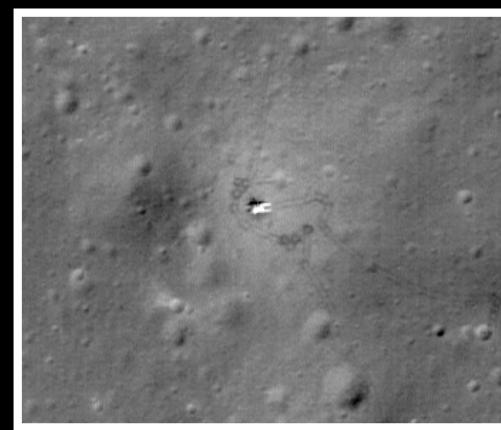
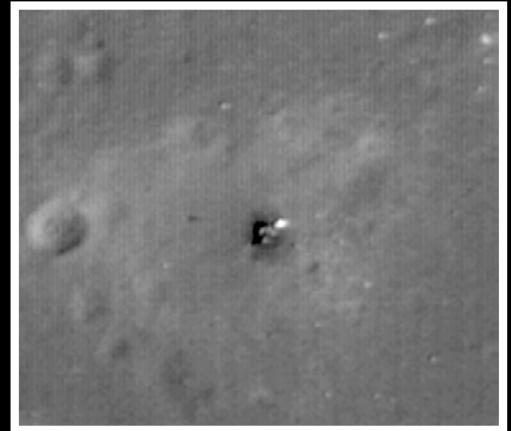
Dark area immediate under and around vehicle

Broader lighter area

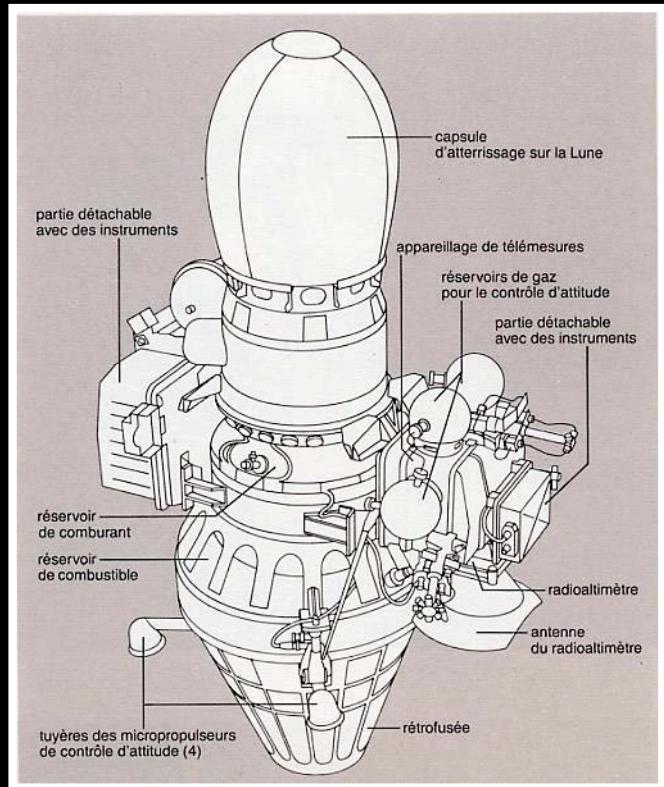
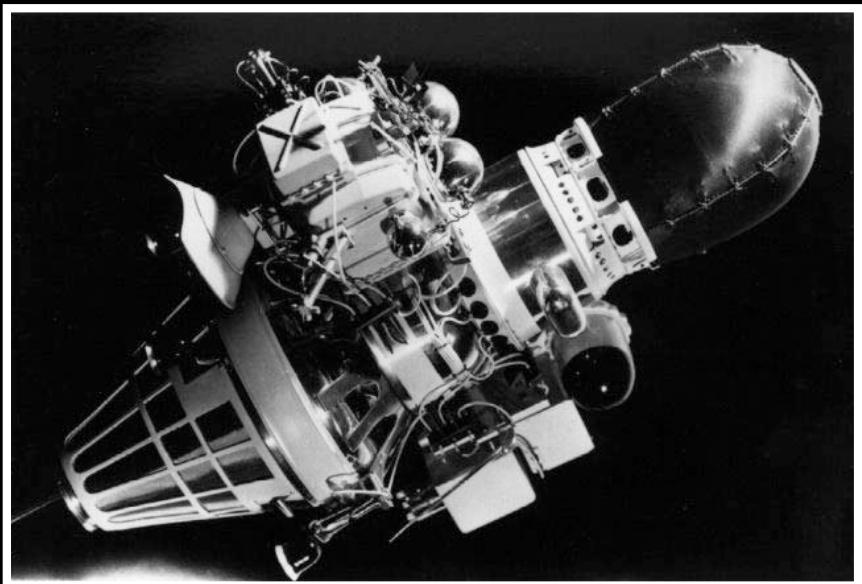
Descent engine erosion.

Erosion of fine-grained material that efficiently backscatters light.

Erosion / deposit to light surface



# Luna 9 / 13



# Lunar Module Ascent Stage

1.68-1.70 km / sec

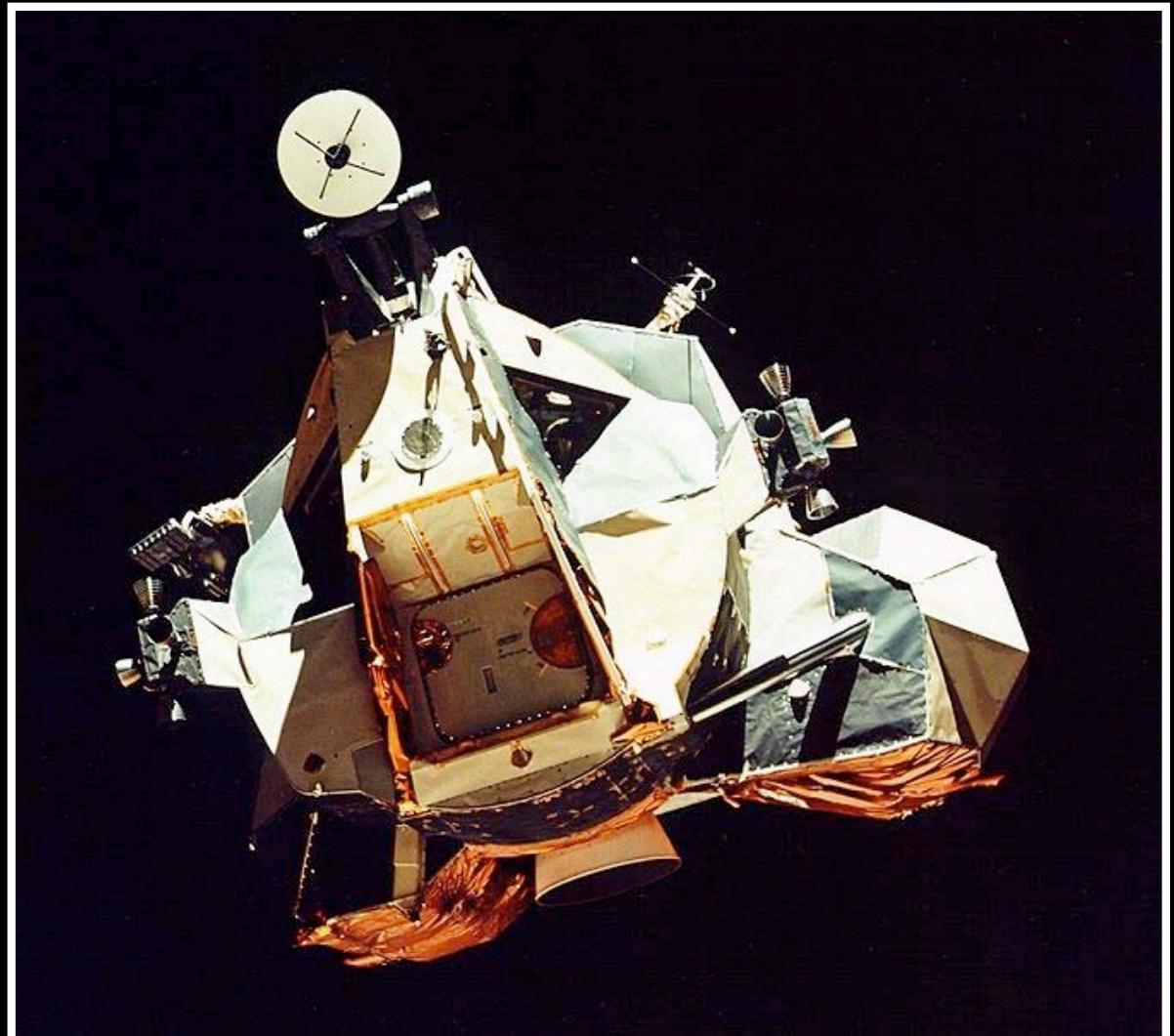
~2300 kg

3.2°-3.7° from horizontal

Expect 18 m crater

These craters may be good analogs for the LCROSS impact (energy, projectile characteristics, but not impact angle).

None found.



## Summary

Surveyor, Luna Sample Returns 16, 20, 23, 24, Luna 17/Lunokhod 1, Luna 21/Lunokhod 2 spacecraft found on lunar surface.

Luna 24 site on ejecta of 63 m crater – explains immature, coarse grained sample.

Lunokhod 1 now observed with LRR – adds significant new data.

Geologic context of surface observations.

Identification of S-IVB impact locations may revise lunar crust velocity models

Thank you.

